



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

|              |   |              |                |
|--------------|---|--------------|----------------|
| Applicant :  | Douglas R. Coffland, et al.                 | Docket No. : | IL-10360       |
| Serial No. : | 09/405,031                                  | Art Unit :   | 2164           |
| Filed :      | 09/24/1999                                  | Examiner :   | Jacob F. Betit |
| For :        | SYSTEM AND METHOD FOR MULTIMEDIA ENCRYPTION |              |                |

**TRANSMITTAL OF APPELLANTS' BRIEF**  
**(PATENT APPLICATION - 37 CFR 192)**

Transmitted herewith is Appellants' Brief in this application with respect to the Notice of Appeal filed on February 7, 2007.

The item(s) checked below are appropriate:

**1. STATUS OF APPLICANT**

This application is on behalf of

☐ other than a small entity.

☒ a small entity.

A verified statement

☐ is attached

☒ already filed.

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|--------------------------|----------------------------------|---|--------------------------------|
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Date: March 30, 2007



**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

**Applicants:** Douglas R. Coffland, et al.

**Attorney Docket No.:** IL-10360

**Group Art Unit:** 2164

**Examiner:** Jacob F. Betit

**Serial No.:** 09/405,031

**Filed:** 09/24/1999

**For:** SYSTEM AND METHOD FOR MULTIMEDIA ENCRYPTION

**Commissioner for Patents  
Alexandria, VA 22313-1450**

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**Kathy Raymond**

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on March 30, 2007

Kathy Raymond  
Kathy Raymond

**PATENT**

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

|              |   |              |                |
|--------------|---|--------------|----------------|
| Applicant :  | Douglas R. Coffland, et al.                 | Docket No. : | IL-10360       |
| Serial No. : | 09/405,031                                  | Art Unit :   | 2164           |
| Filed :      | 09/24/1999                                  | Examiner :   | Jacob F. Betit |
| For :        | SYSTEM AND METHOD FOR MULTIMEDIA ENCRYPTION |              |                |

Honorable Commissioner for Patents  
Alexandria, VA 22313-1450

Attention: Board of Patent Appeals and Interferences

Dear Sir:

**APPELLANTS' BRIEF (37 C.F.R. § 1.192)**

This brief is submitted in support of Appellants' notice of appeal from the decision of the Examiner, mailed November 27, 2006 finally rejecting claims 1-30 of the subject application. Appellants' notice of appeal was mailed February 7, 2007.

One copy of the brief is being transmitted per 37 C.F.R. § 41.37.

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## **I. REAL PARTY IN INTEREST**

The real party in interest is:

The Regents of the University of California and the United States of America as represented by the United States Department of Energy (DOE) by virtue of an assignment by the inventor as duly recorded in the Assignment Branch of the U.S. Patent and Trademark Office.

## **II. RELATED APPEALS AND INTERFERENCES**

There are no related appeals or interferences.

## **III. STATUS OF CLAIMS**

The application as originally filed contained claims 1-30.

The claims on appeal are claims 1-30.

The status of all the claims in the proceeding (*e.g.*, rejected, allowed or confirmed, withdrawn, objected to, canceled) is: "claims 1-30 are rejected."

Claims 1-30 on appeal are reproduced in the Appendix.

## **IV. STATUS OF AMENDMENTS**

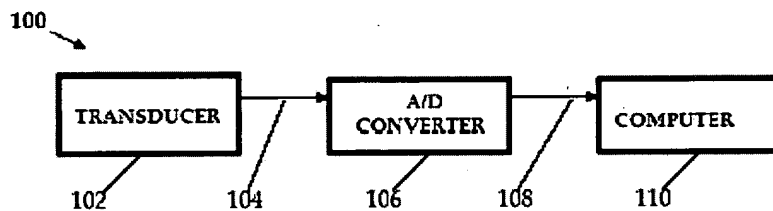
There have been no amendments filed subsequent to the Final Rejection mailed November 27, 2006.

## **V. SUMMARY OF CLAIMED SUBJECT MATTER**

Appellants are providing a concise explanation of the subject matter defined in each of the independent claims involved in the appeal, which refer to

the specification by page and line number, and to the drawing, if any, by reference characters. There are four (4) independent claims involved in the appeal. Appellants' independent claims involved in the appeal are claims 1, 10, 17, and 24.

The invention defined by Appellants' independent claims 1, 10, 17, and 24 is "a system and method adapted for use for multimedia encryption." Figure 1 (below) is a block diagram of a system 100 for multimedia encryption according to the present invention. Within the system 100, a transducer 102, such as a video camera, a radio, a microphone, a Geiger counter, or an electrical component, outputs a media signal 104. (Page 7, lines 2-5)



**FIG. 1**

Within the system of the present invention, a data compression module receives and compresses a media signal into a compressed data stream. A data acquisition module receives and selects a set of data from the compressed data stream. And, a hashing module receives and hashes the set of data into a keyword. (Page 4, lines 2-7)

The elements of Appellants' independent claims 1, 10, 17, and 24 on appeal are "read on" Appellants' original specification. Portions of Appellants' specification are quoted with the specific paragraph containing the quote identified by the page and line numbers being enclosed in parentheses (...).

### Claim 1

1. A system adapted for use for multimedia encryption comprising:

acquisition means for acquiring a media signal, said acquisition means including a random noise transducer for acquiring random noise only, said random noise being unpredictable from one moment to the next and not being chaotic noise;

data compression means coupled to said acquisition means to receive and compress said media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise into a compressed data stream;

data acquisition means coupled to said data compression means to receive and select a set of data from the compressed data stream; and

### Specification & Drawings

Figure 1 is a block diagram of a system 100 for multimedia encryption according to the present invention. (Page 7, lines 2-3)

In one embodiment of the present invention, the media signal need only include random transducer noise having a noise signal amplitude. Random noise is not the same a chaotic noise. Random noise, such as white Gaussian noise, is completely unpredictable from one moment to a next, while chaotic noise is highly predictable over short time periods. (Page 7, lines 10-15)

The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. The converter 106 quantizes the media signal with a quantization step size smaller than the noise signal amplitude within the media signal 104, creating a quantized media signal 108. (Page 7, lines 19-22)

Figure 2 is a graphical depiction of quantization processes within the analog-to-digital converter 106 within the system 100. The media signal 104 is periodically sampled 202. (Page 8, lines 2-4)



Claim 1 (Continued)

hashing means coupled to said data acquisition means to receive and hash the set of data into a keyword.

Specification & Drawings

And, a hashing module receives and hashes the set of data into a keyword. (Page 4, lines 6-7)  
a hashing module coupled to receive and hash the set of data into a keyword. (Page 14, lines 7-8)

Claim 10

10. A method adapted for use for multimedia encryption, comprising the steps of:

acquiring a random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise;

Specification & Drawings

Figure 1 is a block diagram of a system 100 for multimedia encryption according to the present invention. (Page 7, lines 2-3)

In one embodiment of the present invention, the media signal need only include random transducer noise having a noise signal amplitude. Random noise is not the same a chaotic noise. Random noise, such as white Gaussian noise, is completely unpredictable from one moment to a next, while chaotic noise is highly predictable over short time periods. (Page 7, lines 10-15)

#### Claim 10 (Continued)

compressing said random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise;

selecting a set of data from the compressed media signal; and

hashing the set of data into a keyword.

#### Claim 17

17. A system adapted for use for multimedia encryption, comprising:

#### Specification & Drawings

The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. The converter 106 quantizes the media signal with a quantization step size smaller than the noise signal amplitude within the media signal 104, creating a quantized media signal 108. (Page 7, lines 19-22)

Figure 2 is a graphical depiction of quantization processes within the analog-to-digital converter 106 within the system 100. The media signal 104 is periodically sampled 202. (Page 8, lines 2-4)

And, a hashing module receives and hashes the set of data into a keyword. (Page 4, lines 6-7)  
a hashing module coupled to receive and hash the set of data into a keyword. (Page 14, lines 7-8)

#### Specification & Drawings

Figure 1 is a block diagram of a system 100 for multimedia encryption according to the present invention. (Page 7, lines 2-3)

### Claim 17 (Continued)

acquisition means for acquiring a media signal, said acquisition means including a random noise transducer for acquiring said media signal, said random noise transducer acquiring said media signal containing only random noise that is unpredictable from one moment to the next and not being chaotic noise;

data compression means coupled to said acquisition means to receive and compress said media signal containing random noise that is unpredictable from one moment to the next into a compressed data stream;

selection means coupled to said data compression means for selecting a set of data from the compressed data stream; and

hashing means coupled to said selection means for hashing the set of data into a keyword.

### Specification & Drawings

In one embodiment of the present invention, the media signal need only include random transducer noise having a noise signal amplitude. Random noise is not the same as chaotic noise. Random noise, such as white Gaussian noise, is completely unpredictable from one moment to the next, while chaotic noise is highly predictable over short time periods. (Page 7, lines 10-15)

The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. The converter 106 quantizes the media signal with a quantization step size smaller than the noise signal amplitude within the media signal 104, creating a quantized media signal 108. (Page 7, lines 19-22)

Figure 2 is a graphical depiction of quantization processes within the analog-to-digital converter 106 within the system 100. The media signal 104 is periodically sampled 202. (Page 8, lines 2-4)

And, a hashing module receives and hashes the set of data into a keyword. (Page 4, lines 6-7)  
a hashing module coupled to receive and hash the set of data into a keyword. (Page 14, lines 7-8)

## Claim 24

24. A computer-useable medium embodying computer program code adapted for use for multimedia encryption by executing the steps of:

acquiring a random noise only media signal, said random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise;

compressing said random noise only media signal, said random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise;

selecting a set of data from the compressed media signal; and

## Specification & Drawings

Figure 1 is a block diagram of a system 100 for multimedia encryption according to the present invention. (Page 7, lines 2-3)

In one embodiment of the present invention, the media signal need only include random transducer noise having a noise signal amplitude. Random noise is not the same a chaotic noise. Random noise, such as white Gaussian noise, is completely unpredictable from one moment to a next, while chaotic noise is highly predictable over short time periods. (Page 7, lines 10-15)

The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. The converter 106 quantizes the media signal with a quantization step size smaller than the noise signal amplitude within the media signal 104, creating a quantized media signal 108. (Page 7, lines 19-22)

Figure 2 is a graphical depiction of quantization processes within the analog-to-digital converter 106 within the system 100. The media signal 104 is periodically sampled 202. (Page 8, lines 2-4)

Claim 24 (Continued)

Specification & Drawings

hashing the set of data into a keyword.

And, a hashing module receives and hashes the set of data into a keyword. (Page 4, lines 6-7)  
a hashing module coupled to receive and hash the set of data into a keyword. (Page 14, lines 7-8)

Of Appellants' four independent claims involved in the appeal, only two include means plus function as permitted by 35 U.S.C. § 112, sixth paragraph. Appellants' two independent claims involved in the appeal that include means plus function are independent claims 1 and 17. For independent claims 1 and 17, Appellants' are providing a concise explanation of the structure, material, or acts described in the specification as corresponding to each claimed function with reference to the specification by page and line number, and to the drawing, if any, by reference characters.

Claim 1 Means plus Function

Explanation of Structure, Material, or Acts

acquisition means for acquiring a media signal, said acquisition means including a random noise transducer for acquiring random noise only, said random noise being unpredictable from one moment to the next and not being chaotic noise;

Figure 1 is a block diagram of a system 100 for multimedia encryption according to the present invention. Within the system 100, a transducer 102, such as a video camera, a radio, a microphone, a Geiger counter, or an electrical component, outputs a media signal 104. (FIG. 1 and Page 7, lines 1-5)  
The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. (FIG. 1 and Page 7, lines 19-20)  
the media signal need only include random transducer noise having a noise signal amplitude. Random noise is not the same as chaotic noise. Random noise, such as white Gaussian noise, is completely unpredictable from one moment to a next, while chaotic noise is highly predictable over short time periods. (Page 7, lines 10-15)

Claim 1 Means plus Function

data compression means coupled to said acquisition means to receive and compress said media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise into a compressed data stream;

data compression means coupled to said acquisition means to receive and compress said media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise into a compressed data stream;

hashing means coupled to said data acquisition means to receive and hash the set of data into a keyword.

Explanation of Structure, Material, or Acts

The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. The converter 106 quantizes the media signal with a quantization step size smaller than the noise signal amplitude within the media signal 104, creating a quantized media signal 108. (FIG. 1 and Page 7, lines 19-22)

The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. The converter 106 quantizes the media signal with a quantization step size smaller than the noise signal amplitude within the media signal 104, creating a quantized media signal 108. (FIG. 1 and Page 7, lines 19-22)

And, a hashing module receives and hashes the set of data into a keyword. (Page 4, lines 6-7)  
a hashing module coupled to receive and hash the set of data into a keyword. (Page 14, lines 7-8)

Claim 17 Means plus Function

acquisition means for acquiring a media signal, said acquisition means including a random noise transducer for acquiring said media signal, said random noise transducer acquiring said media signal containing only random noise that is unpredictable from one moment to the next and not being chaotic noise;

data compression means coupled to said acquisition means to receive and compress said media signal containing random noise that is unpredictable from one moment to the next into a compressed data stream;

Explanation of Structure, Material, or Acts

Figure 1 is a block diagram of a system 100 for multimedia encryption according to the present invention. Within the system 100, a transducer 102, such as a video camera, a radio, a microphone, a Geiger counter, or an electrical component, outputs a media signal 104. (FIG. 1 and Page 7, lines 1-5)

The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. (FIG. 1 and Page 7, lines 19-20)

the media signal need only include random transducer noise having a noise signal amplitude. Random noise is not the same as chaotic noise. Random noise, such as white Gaussian noise, is completely unpredictable from one moment to a next, while chaotic noise is highly predictable over short time periods. (Page 7, lines 10-15)

The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. The converter 106 quantizes the media signal with a quantization step size smaller than the noise signal amplitude within the media signal 104, creating a quantized media signal 108. (FIG. 1 and Page 7, lines 19-22)

| <u>Claim 17 Means plus Function</u>   | <u>Explanation of Structure, Material, or Acts</u>   |
|---|--|
| selection means coupled to said data compression means for selecting a set of data from the compressed data stream; | The media signal 104 from the transducer 102 is fed into an analog-to-digital (A/D) converter 106. The converter 106 quantizes the media signal with a quantization step size smaller than the noise signal amplitude within the media signal 104, creating a quantized media signal 108. (FIG. 1 and Page 7, lines 19-22) |
| hashing means coupled to said selection means for hashing the set of data into a keyword.                           | And, a hashing module receives and hashes the set of data into a keyword. (Page 4, lines 6-7)<br>a hashing module coupled to receive and hash the set of data into a keyword. (Page 14, lines 7-8)   |

## VI. GROUNDS OF REJECTION TO BE REVIEWED ON APPEAL

The Final Rejection mailed November 27, 2006 states four grounds of rejection. The four grounds of rejection are summarized below.

**Ground of Rejection #1** - Claims 1-30 were rejected under 35 U.S.C. § 112, first paragraph, as failing to comply with the written description requirement.

**Ground of Rejection #2** - Claims 1-30 were rejected under 35 U.S.C. § 112, first paragraph, as based on a disclosure which is not enabling.

**Ground of Rejection #3** - Claims 1-30 were rejected under 35 U.S.C. § 112, second paragraph, as being incomplete for omitting essential steps, elements or instructions.

**Ground of Rejection #4** - Claims 1-23 were rejected under 35 U.S.C. § 101, because the claimed invention is directed to non-statutory subject matter.



## VII. ARGUMENT

Appellants present arguments directed to the four separate grounds of rejection in the order that the four separate grounds of rejection are stated in the Final Rejection mailed November 27, 2006.

**Ground of Rejection #1** - Claims 1-30 were rejected under 35 U.S.C. § 112, first paragraph, as failing to comply with the written description requirement.

The Final Rejection mailed November 27, 2006 states:

"Claims 1-30 are rejected under 35 U.S.C. § 112, first paragraph, as failing to comply with the written description requirement. The claim(s) contain subject matter which was not described in the specification in such a way as to reasonably convey to one skilled in the relevant art that the inventor(s), at the time the application was filed, had possession of the claimed invention. Claims 1, 10, 17, and 24 recite limitation 'random noise being unpredictable from one moment to the next.' This limitation is not described in the specification in such a way as to reasonably convey to one skilled in the relevant art that the inventor(s), at the time the application was filed, had possession of the claimed invention."

### **Limitation Was Described In Original Specification**

The limitation was described in the original specification in such a way as to reasonably convey to one skilled in the relevant art that the inventors had possession of the claimed invention.

The relevant limitation in the four independent claims, claims 1, 10, 17, and 24 set out below.

Relevant limitation in claim 1: "said acquisition means including a random noise transducer for acquiring random noise only, said random noise being unpredictable from one moment to the next and not being chaotic noise."

Relevant limitation in claim 10: "acquiring a random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise."

Relevant limitation in claim 17: "acquisition means for acquiring a media signal, said acquisition means including a random noise transducer for acquiring said media signal, said random noise transducer acquiring said media signal containing only random noise that is unpredictable from one moment to the next and not being chaotic noise."

Relevant limitation in claim 24: "acquiring a random noise only media signal, said random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise."

Appellants believe it is clear from the original specification that a person skilled in the art would recognize that the inventor had possession of the claimed invention including the claim limitation "random noise being unpredictable from one moment to the next" of claims 1, 10, 17, and 24. The limitation "random noise being unpredictable from one moment to the next" of Claims 1, 10, 17, and 24 and Appellants' original specification are compared below.

The Limitation

random noise being  
unpredictable from one  
moment to the next

Appellants' Original Specification

In one embodiment of the present invention, the media signal need only include random transducer noise having a noise signal amplitude. Random noise is not the same as chaotic noise. Random noise, such as white Gaussian noise, is completely unpredictable from one moment to a next, while chaotic noise is highly predictable over short time periods. (Page 7, lines 10-15 of Appellants' Original Specification)

Appellants' specification discusses and describes "random noise" throughout the application. Appellants' specification in connection with FIG. 2 states, "The random noise in the media signal 104 will cause even unchanging video scenes to have quantization values 206 which fluctuate for media signal values close to one or more quantization steps 204. .... Typically, the transducer noise is sufficient to cause the quantization values 206 to fluctuate. However, if the transducer noise is small relative to the quantization steps 204, then either video or audio content of the media signal 104 must vary somewhat so that what little noise is in the scene will enable random noise to be quantized by the A/D converter 106. Randomness will be present in the media signal 104 when an actual sampled media signal value 208 is very close to a quantization boundary 210."

A person skilled in the art would recognize that the inventor had possession of the claimed invention including the claim limitation "random noise being unpredictable from one moment to the next" of claims 1, 10, 17, and 24. The concepts and fundamentals of "random noise" were well known in the prior art at the time Applicants filed their patent application. For example, the October 16, 1998 publication "DESIGN OF RANDOM NOISE GENERATOR USING SW ALGORITHM" by Jinkeun Hong, Sunchun Park, Janghong Yoon, Jaeyoung Koh, and Daeho Kim and the publication cited in the article describe concepts and fundamentals of "random noise." The October 16, 1998 publication "DESIGN OF RANDOM NOISE GENERATOR USING SW ALGORITHM" by Jinkeun Hong, Sunchun Park, Janghong Yoon, Jaeyoung Koh, and Daeho Kim is attached in the EVIDENCE APPENDIX.

### **Person Skilled In The Art**

The level of skill of a person skilled in the relevant art is very high being scientists with BS degrees in electrical engineering or computer sciences and advanced degrees in electrical engineering or computer sciences. The lead inventor, Douglas R. Coffland, is Division Leader - Security Engineering and Computation Division of the Lawrence Livermore National Laboratory. The Lawrence Livermore National Laboratory (LLNL) is a premier applied science laboratory that is part of the National Nuclear Security Administration (NNSA) within the Department of Energy (DOE). The LLNL website states that LLNL employs 6,600 full-time employees, including 2,681 scientists and engineers of which 1,212 hold Ph.D degrees. The *Wikipedia, the free encyclopedia* encyclopedia describes the Lawrence Livermore National Laboratory. The *Wikipedia, the free encyclopedia* description of the Lawrence Livermore National Laboratory is attached in the EVIDENCE APPENDIX.

The Lawrence Livermore National Laboratory computer operations are the best in the world. According to recent TOP500 lists, Computation operates some of the world's fastest supercomputers: BlueGene/L, a cooperative project to design and build a computer architecture capable of scaling to hundreds of teraflops (TF); ASC Purple, a genuinely huge machine based on symmetric shared-memory multiprocessors containing more than 12,000 next-generation IBM Power5 microprocessors and capable of 100 TF; and Thunder (right), a highly integrated, well-balanced capability compute resource with 1,024 nodes and a theoretical system peak performance of 22.9 TF. Copies of two pages from the Lawrence Livermore National Laboratory website [www.llnl.gov](http://www.llnl.gov) are attached in the EVIDENCE APPENDIX.

Encryption is of high importance to the National Nuclear Security Administration (NNSA), the Department of Energy (DOE), and the Lawrence

Livermore National Laboratory. The lead inventor, Douglas R. Coffland, as Division Leader - Security Engineering and Computation Division of the Lawrence Livermore National Laboratory is highly skilled in Encryption. The lead inventor, Douglas R. Coffland, as Division Leader - Security Engineering and Computation Division of the Lawrence Livermore National Laboratory had possession of the claimed invention including the claim limitation "random noise being unpredictable from one moment to the next" of claims 1, 10, 17, and 24.

Appellants' specification taken as a whole supports the claim limitation. MPEP §2163 II.A.3 states, "An adequate written description of the invention may be shown by any description of sufficient, relevant, identifying characteristics so long as a person skilled in the art would recognize that the inventor had possession of the claimed invention."

There is a strong presumption that an adequate written description of the claimed invention is present when the application is filed. In *re Wertheim*, 541 F.2d 257, 263, 191 USPQ 90, 97 (CCPA 1976), the implication stated in the Final Rejection is contradicted by Appellants' specification taken as a whole. The implication stated in the Final Rejection is not sufficient to overcome the presumption that an adequate written description of the claimed invention is present when the application is filed.

The rejection of claims 1-30 under 35 U.S.C. § 112, first paragraph, as failing to comply with the written description requirement of Ground of Rejection #1 should be reversed.

**Ground of Rejection #2** - Claims 1-30 were rejected under 35 U.S.C. § 112, first paragraph, as allegedly based on a disclosure which is not enabling. The Final Rejection mailed November 27, 2006 states:

"Multimedia encryption critical or essential to the practice of the invention, but not included in the claim(s) is not enabled by the disclosure. See *In re Mayhew*, 527 F.2d 1229, 188 USPQ 356 (CCPA 1976). The preamble of claims 1 and 17 state 'a system for multimedia encryption.' The preamble of claim 10 states 'a method for multimedia encryption.' The preamble for claim 24 states 'a computer-usable medium embodying computer program code for multimedia encryption.' Both the specification and the claims disclose steps for producing a keyword which could be used as a key for encryption or a key for generating pseudo-random numbers that are later used in encryption, however, neither the specification nor the claims disclose any steps, elements or instructions that encrypt multimedia."

The concepts and fundamentals of term "multimedia encryption" were well known in the prior art at the time Appellants filed their patent application. The term "multimedia encryption" is part of the title of the subject application and is used throughout the patent application. Appellant's original specification describes the claimed invention sufficiently to enable one skilled in the relevant art to practice the invention and meets the requirements of 35 U.S.C. § 112, first paragraph.

Dr. Borko Furht, Chairman & Professor Department of Computer Science and Engineering, Florida Atlantic University, Boca Raton, FL had written numerous publications discussing the concepts and fundamentals of term "multimedia encryption" at the time Appellants filed their patent application. A list of Dr. Borko's publications and a copy of the publication "Fundamentals of Multimedia Encryption Techniques" by Dr. Borko are attached in the EVIDENCE APPENDIX. Dr. Borko Furht's main areas of research were: "Image and video coding and processing," "Wireless multimedia technologies," and "Secure multimedia communications."

### **Person Skilled In The Art**

The level of skill of a person skilled in the relevant art is very high being scientists with BS degrees in electrical engineering or computer sciences and advanced degrees in electrical engineering or computer sciences. The lead inventor, Douglas R. Coffland, is Division Leader - Security Engineering and Computation Division of the Lawrence Livermore National Laboratory. The Lawrence Livermore National Laboratory (LLNL) is a premier applied science laboratory that is part of the National Nuclear Security Administration (NNSA) within the Department of Energy (DOE). The LLNL website states that LLNL employs 6,600 full-time employees, including 2,681 scientists and engineers of which 1,212 hold Ph.D degrees. The *Wikipedia, the free encyclopedia* encyclopedia describes the Lawrence Livermore National Laboratory. The *Wikipedia, the free encyclopedia* description of the Lawrence Livermore National Laboratory is attached in the EVIDENCE APPENDIX.

There is a strong presumption that an adequate written description of the claimed invention is present when the application is filed. In re Wertheim, 541 F.2d 257, 263, 191 USPQ 90, 97 (CCPA 1976). Appellant's original specification contains an adequate written description of the claimed invention for a person skilled in the art to practice the claimed invention. Also, the concepts and fundamentals of term "multimedia encryption" were well known in the prior art at the time Appellants filed their patent application. Appellant submits that, based upon the original specification, a person skilled in the art could practice the claimed invention.

The 35 U.S.C. § 112, first paragraph, rejection of claims 1-30 as based on a disclosure which is not enabling of Ground of Rejection #2 should be reversed.

**Ground of Rejection #3** - Claims 1-30 were rejected under 35 U.S.C. § 112, second paragraph, as allegedly being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention and as allegedly being incomplete for omitting essential steps, elements or instructions. The Office Action mailed November 27, 2006 stated:

"See MPEP § 2172.01. The preamble of claims 1 and 17 state 'a system adapted for use for multimedia encryption.' The preamble of claim 10 states 'a method adapted for use for multimedia encryption.' The preamble for claim 24 states 'a computer-usable medium embodying computer program code adapted for use for multimedia encryption.' However the steps, elements, or instructions of the claims disclose creating a keyword. The claims omit the steps, elements, or instructions of actually encrypting any multimedia data."

Appellants' claimed invention defined by independent claim 1 is "a system adapted for use for multimedia encryption." Claim 1 includes a combination of structural elements that produce the system adapted for use for multimedia encryption. The structural elements include "acquisition means for acquiring a media signal," "data compression means coupled to said acquisition means to receive and compress said media signal," "data acquisition means coupled to said data compression means to receive and select a set of data from the compressed data stream," and "hashing means coupled to said data acquisition means to receive and hash the set of data into a keyword." These structural elements produce the system adapted for use for multimedia encryption. There are no essential structural elements omitted.

Appellants' submits that claim 1 describes the invention sufficiently and particularly points out and distinctly claims the subject matter which applicant regards as the invention, claim 1 is not incomplete for omitting essential elements, and claim 1 meets the requirements of 35 U.S.C. § 112, second paragraph.



Appellants' claimed invention defined by independent claim 10 is "a method adapted for use for multimedia encryption." Claim 10 includes a combination of steps. The steps include "acquiring a random noise only media signal," "compressing said random noise only media signal," "selecting a set of data from the compressed media signal," and "hashing the set of data into a keyword." There are no essential steps omitted.

Appellants' submits that claim 10 describes the invention sufficiently and particularly points out and distinctly claims the subject matter which applicant regards as the invention, claim 10 is not incomplete for omitting essential steps, and claim 10 meets the requirements of 35 U.S.C. § 112, second paragraph.

Appellants' claimed invention defined by independent claim 17 is "a system adapted for use for multimedia encryption." Claim 17 includes a combination of structural elements that produce the system adapted for use for multimedia encryption. The structural elements include "acquisition means for acquiring a media signal," "data compression means coupled to said acquisition means to receive and compress said media signal," "selection means coupled to said data compression means for selecting a set of data from the compressed data stream," and "hashing means coupled to said selection means for hashing the set of data into a keyword." These structural elements produce the system adapted for use for multimedia encryption. There are no essential structural elements omitted.

Appellants' submits that claim 17 describes the invention sufficiently and particularly points out and distinctly claims the subject matter which applicant regards as the invention, claim 17 is not incomplete for omitting essential elements, and claim 17 meets the requirements of 35 U.S.C. § 112, second paragraph.

Appellants' claimed invention defined by independent claim 24 is "a computer-useable medium embodying computer program code adapted for use for multimedia encryption by executing the steps." Claim 24 includes a combination of steps. The steps include "acquiring a random noise only media signal," "compressing said random noise only media signal," "selecting a set of data from the compressed media signal," and "hashing the set of data into a keyword." The steps produce the computer-useable medium embodying computer program code adapted for use for multimedia encryption. There are no essential steps omitted.

Appellants' submits that claim 24 describes the invention sufficiently and particularly points out and distinctly claims the subject matter which applicant regards as the invention, claim 24 is not incomplete for omitting essential steps, and claim 24 meets the requirements of 35 U.S.C. § 112, second paragraph.

The rejection of claims 1-30 under 35 U.S.C. § 112, first paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention and as allegedly being incomplete for omitting essential steps, elements or instructions of Ground of Rejection #3 should be reversed.

**Ground of Rejection #4** - Claims 1-23 were rejected under 35 U.S.C. § 101 because allegedly the claimed invention is directed to non-statutory subject matter. The Final Rejection stated:

"The claims do not recite a practical application by producing a physical transformation or producing a useful, concrete, and tangible result. To perform a physical transformation, the claimed invention must transform an article of physical object into a different state or thing. Transformation of data is not a physical transformation. A useful, concrete, and tangible result

must be either specifically recited in the claim or flow inherently therefrom. To be useful the claimed invention must establish a specific, substantial, and credible utility. To be concrete the claimed invention must be able to produce the same results given the same initial starting conditions. To be tangible the claimed invention must produce a practical application or real world result. In this case the claims fail to perform a physical transformation because the claims are directed to operating on data. The claims are useful and concrete, but they fail to produce a tangible result because the keyword is never presented for use by another process or the user and is never stored."

Appellants' claimed invention defined by independent claim 1 is "a system adapted for use for multimedia encryption." Claim 1 includes a combination of structural elements that produce the system adapted for use for multimedia encryption. The structural elements include "acquisition means for acquiring a media signal," "data compression means coupled to said acquisition means to receive and compress said media signal," "data acquisition means coupled to said data compression means to receive and select a set of data from the compressed data stream," and "hashing means coupled to said data acquisition means to receive and hash the set of data into a keyword."

The Examiner's allegation that the claims "fail to produce a tangible result because the keyword is never presented for use by another process or the user and is never stored" is not sufficient to render the claimed invention to be non-statutory subject matter. The structural element of claim 1, "hashing means coupled to said data acquisition means to receive and hash the set of data into a keyword" is one structural element of an apparatus comprising the combination of structural elements of claim 1. These structural elements produce and apparatus adapted for use for multimedia encryption. That use flows inherently from the apparatus.

The structural elements of claim 1 produce an apparatus that is useful. Applicant's original specification page 4, lines 19-22 and page 5, lines 1-2 states,

"The system/apparatus and method of the present invention are particularly advantageous over the prior art because a means of capturing random numbers for encryption seeding directly from variable frame boundary compressed data is disclosed. In light of a growing importance in securely transmitting multimedia data over digital networks, obtaining random numbers directly from the multimedia data would be very useful."

Appellants' claimed invention defined by independent claim 10 is "a method adapted for use for multimedia encryption." Claim 10 includes a combination of steps. The steps include "acquiring a random noise only media signal," "compressing said random noise only media signal," "selecting a set of data from the compressed media signal," and "hashing the set of data into a keyword." These method steps produce a tangible result and the result is useful. Applicant's original specification page 4, lines 19-22 and page 5, lines 1-2 states, "The system/apparatus and method of the present invention are particularly advantageous over the prior art because a means of capturing random numbers for encryption seeding directly from variable frame boundary compressed data is disclosed. In light of a growing importance in securely transmitting multimedia data over digital networks, obtaining random numbers directly from the multimedia data would be very useful."

The Examiner's allegation that the claims "fail to produce a tangible result because the keyword is never presented for use by another process or the user and is never stored" is not sufficient to render the claimed invention to be non-statutory subject matter. The method steps of claim 10 result in method adapted for use for multimedia encryption. That use flows inherently from the method.

Appellants' claimed invention defined by independent claim 17 is "a system adapted for use for multimedia encryption." Claim 17 includes a

combination of structural elements that produce the system adapted for use for multimedia encryption. The structural elements include "acquisition means for acquiring a media signal," "data compression means coupled to said acquisition means to receive and compress said media signal," "selection means coupled to said data compression means for selecting a set of data from the compressed data stream," and "hashing means coupled to said selection means for hashing the set of data into a keyword."

The Examiner's allegation that the claims "fail to produce a tangible result because the keyword is never presented for use by another process or the user and is never stored" is not sufficient to render the claimed invention to be non-statutory subject matter. The structural element of claim 17, "hashing means coupled to said data acquisition means to receive and hash the set of data into a keyword" is one structural element of an apparatus comprising the combination of structural elements of claim 17. These structural elements produce and apparatus adapted for use for multimedia encryption. That use flows inherently from the apparatus.

The structural elements of claim 17 produce an apparatus that is useful. Applicant's original specification page 4, lines 19-22 and page 5, lines 1-2 states, "The system/apparatus and method of the present invention are particularly advantageous over the prior art because a means of capturing random numbers for encryption seeding directly from variable frame boundary compressed data is disclosed. In light of a growing importance in securely transmitting multimedia data over digital networks, obtaining random numbers directly from the multimedia data would be very useful."

The rejection of claims 1-23 under 35 U.S.C. § 101 because the claimed invention is directed to non-statutory subject matter of Ground of Rejection #4 should be reversed.

Appellants' invention defined by claims 1-30 on appeal provides a system and method adapted for use for multimedia encryption that complies with the written description requirement, is based on a disclosure which is enabling, includes all essential steps, elements, and instructions, and is directed to statutory subject matter. It is respectfully requested that claims 1-30 on appeal be allowed.

Respectfully submitted,

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Date: March 30, 2007

## VIII. CLAIMS APPENDIX

1. A system adapted for use for multimedia encryption comprising:

acquisition means for acquiring a media signal, said acquisition means including a random noise transducer for acquiring random noise only, said random noise being unpredictable from one moment to the next and not being chaotic noise;

data compression means coupled to said acquisition means to receive and compress said media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise into a compressed data stream;

data acquisition means coupled to said data compression means to receive and select a set of data from the compressed data stream; and

hashing means coupled to said data acquisition means to receive and hash the set of data into a keyword.

2. The system of claim 1 wherein the set of data is one frame of data within the compressed data stream.

3. The system of claim 1 wherein the set of data crosses over several frame boundaries within the compressed data stream.

4. The system of claim 1 wherein: the compressed data stream includes compression transform coefficients; and the set of data includes a set of compression transform coefficients.

5. The system of claim 1 wherein: the compressed data stream includes data frames of varying length; and the set of data includes a set of data frames.

6. The system of claim 1 wherein: the compressed data stream includes predictive data frames; and the set of data includes a predictive data frame.

7. The system of claim 1: wherein the media signal includes a noise signal amplitude; further comprising, an analog to digital converter, having a

quantization step size smaller than the noise signal amplitude, coupled to receive and quantize the media signal; and wherein the data compression module compresses the quantized media signal into a compressed data stream.

8. The system of claim 1 wherein the data compression module compresses the media signal into one from a group consisting of: MJPEG, MPEG1, MPEG2, or MPEG4, H.261, H.320, and H.323 formats.

9. The system of claim 1 further comprising: a pseudo-random number generator coupled to receive and process the keyword in to a set of keywords.

10. A method adapted for use for multimedia encryption, comprising the steps of:

acquiring a random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise;

compressing said random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise;

selecting a set of data from the compressed media signal; and

hashing the set of data into a keyword.

11. The method of claim 10 wherein: the compressed media signal includes data frames; and the selecting step includes the step of selecting one frame of data.

12. The method of claim 10 wherein: the compressed media signal includes data frames and data frame boundaries; and the selecting step includes the step of selecting a set of data which crosses over several data frame boundaries.

13. The method of claim 10 wherein: the compressed media signal includes compression transform coefficients; and the selecting step includes the step of selecting a set of compression transform coefficients.



14. The method of claim 10 wherein: the compressed media signal includes data frames of varying length; and the selecting step includes the step of selecting a set of data frames.

15. The method of claim 10 wherein: the compressed media signal includes predictive data frames; and the selecting step includes the step of selecting a predictive data frame.

16. The method of claim 10: wherein the media signal includes a noise signal amplitude; further comprising the step of quantizing the media signal with a quantization step size smaller than the noise signal amplitude; and wherein the compressing step includes the step of compressing the quantized media signal.

17. A system adapted for use for multimedia encryption, comprising:  
acquisition means for acquiring a media signal, said acquisition means including a random noise transducer for acquiring said media signal, said random noise transducer acquiring said media signal containing only random noise that is unpredictable from one moment to the next and not being chaotic noise;

data compression means coupled to said acquisition means to receive and compress said media signal containing random noise that is unpredictable from one moment to the next into a compressed data stream;

selection means coupled to said data compression means for selecting a set of data from the compressed data stream; and

hashing means coupled to said selection means for hashing the set of data into a keyword.

18. The system of claim 17 wherein: the compressed media signal includes data frames; and the means for selecting includes means for selecting one frame of data.

19. The system of claim 17 wherein: the compressed media signal includes data frames and data frame boundaries; and the means for selecting includes means for selecting a set of data which crosses over several data frame boundaries.

20. The system of claim 17 wherein: the compressed media signal includes compression transform coefficients; and the means for selecting includes means for selecting a set of compression transform coefficients.

21. The system of claim 17 wherein: the compressed media signal includes data frames of varying length; and the means for selecting includes means for selecting a set of data frames.

22. The system of claim 17 wherein: the compressed media signal includes predictive data frames; and the means for selecting includes means for selecting a predictive data frame.

23. The system of claim 17: wherein the media signal includes a noise signal amplitude; further comprising means for quantizing the media signal with a quantization step size smaller than the noise signal amplitude; and wherein the means for compressing includes means for compressing the quantized media signal.

24. A computer-useable medium embodying computer program code adapted for use for multimedia encryption by executing the steps of:

acquiring a random noise only media signal, said random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise;

compressing said random noise only media signal, said random noise only media signal containing random noise that is unpredictable from one moment to the next and not being chaotic noise;

selecting a set of data from the compressed media signal; and

hashing the set of data into a keyword.

25. The computer-useable medium of claim 24 wherein: the compressed media signal includes data frames; and the selecting step includes the step of selecting one frame of data.

26. The computer-useable medium of claim 24 wherein: the compressed media signal includes data frames and data frame boundaries; and the selecting step includes the step of selecting a set of data which crosses over several data frame boundaries.

27. The computer-useable medium of claim 24 wherein: the compressed media signal includes compression transform coefficients; and the selecting step includes the step of selecting a set of compression transform coefficients.

28. The computer-useable medium of claim 24 wherein: the compressed media signal includes data frames of varying length; and the selecting step includes the step of selecting a set of data frames.

29. The computer-useable medium of claim 24 wherein: the compressed media signal includes predictive data frames; and the selecting step includes the step of selecting a predictive data frame.

30. The computer-useable medium of claim 24: wherein the media signal includes a noise signal amplitude; further comprising the step of quantizing the media signal with a quantization step size smaller than the noise signal amplitude; and wherein the compressing step includes the step of compressing the quantized media signal.

## IX. EVIDENCE APPENDIX

Evidence Appendix Document #1 - Publication "DESIGN OF RANDOM NOISE GENERATOR USING SW ALGORITHM" by Jinkeun Hong, Sunchun Park, Janghong Yoon, Jaeyoung Koh, and Daeho Kim:

Evidence Appendix Document #2 - *Wikipedia, the free encyclopedia* description of the Lawrence Livermore National Laboratory.

Evidence Appendix Document #3 - three pages from the Lawrence Livermore National Laboratory website [www.llnl.gov](http://www.llnl.gov).

Evidence Appendix Document #4 - List of Dr. Borko's Publications.

Evidence Appendix Document #5 - Publication "Fundamentals of Multimedia Encryption Techniques" by Dr. Borko.

## **X. RELATED PROCEEDINGS APPENDIX**

There are no entries in the Related Proceedings Appendix.

# DESIGN OF RANDOM NOISE GENERATOR USING SW ALGORITHM

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## ABSTRACT

A random noise generator uses a non-deterministic source to produce randomness. Most operate by measuring unpredictable natural processes, such as thermal noise, atmospheric noise, or nuclear decay. Critical cryptography applications require the production of an unpredictable and unbiased stream of binary data derived from a fundamental noise mechanism. In this paper, we proposed a random noise generator with Gaussian noise using filtering algorithm. The proposed scheme is designed to reduce the statistical property of the biased bit stream in the output of a random noise generator.

**Keywords:** *Random Noise generator, Gaussian Noise Source, randomness.*

## 1. INTRODUCTION

More demanding random noise applications, such as cryptography and statistical simulation, benefit from sequences produced by a random noise generator, a cryptographic system based on a hardware component [1]. A real noise generator is a source of unpredictable, irreproducible, and statistically random stream sequences. A popular method for generating random numbers using a natural phenomenon is the electronic amplification and sampling of a thermal or Gaussian noise signal. Since all electronic systems are influenced by a finite bandwidth,  $1/f$  noise, and other non-random influences, perfect randomness cannot be preserved by any practical system. Thus, when generating random numbers using an electronic circuit, a low-power white noise signal is amplified, and then sampled at a constant sampling frequency. However, it is quite difficult to create an unbiased and stable random bit stream, as required for statistical randomness, when using a random generator with only a hardware component. The studies reported in [2-4] show that the randomness of a random stream can be enhanced when combining a random noise generator and hash function (or LFSR). However, the randomness of this combined method is still dependent on the security level of the hash function (or LFSR). Accordingly, the current paper proposes a random noise generator that combines a random noise generator and filtering technique that is not dependent on the security level of the period. First, the proposed random noise generator is introduced, followed by the hardware system. Finally, experimental results using the proposed system are presented.

## 2. DESIGN FOR PROPOSED REAL RANDOM NOISE GENERATOR

Random noise generators include common components for producing random bit-streams, classified as follows: characteristics of the noise source, amplification of the noise source, and sampling for gathering the comparator output.

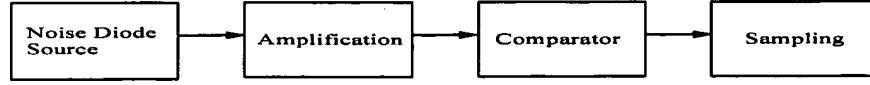


Fig.1. Random Noise generator

### 2.1 Characteristics of Noise Source

The applied noise source uses Gaussian noise, which typically results from the flow of electrons through a highly charged field, such as a semiconductor junction. Ultimately, the electron flow is the movement of discrete charges, and the mean flow rate is surrounded by a distribution related to the launch time and momentum of the individual charge carriers entering the charged field. The Gaussian noise generated in a PN junction has the same mathematical form as that of a temperature-limited vacuum diode. The noise seems to be generated by the noise current generator in parallel with the dynamic resistance of the diode.

$$I_{ns} = (2 e I_{dc} B)^{1/2} \quad (1)$$

Where  $e$ = Electron charge ( $1.6 \times 10^{-19}$  coulombs),  $I_{dc}$ = Average dc current (A),  $B$ =Noise bandwidth (Hz). The Gaussian noise voltage can be determined by applying Ohms Law.

$$E_{ns} = (2 e I_{dc} B r_d^2)^{1/2} \quad (2)$$

Where,  $r_d$  is the dynamic resistance of the junction.

It is known that the dynamic resistance of a PN junction depends on the temperature and direct current flowing through the junction. The dynamic resistance represents the ratio of a small change in the diode voltage to the corresponding change in the diode current.

$$r_d = kT/eI_{dc} \quad (3)$$

Substituting produces

$$E_{ns} = (2kTB r_d)^{1/2} \quad (4)$$

Substituting again produces

$$E_{ns} = kT(2/eI_{dc})^{1/2} \quad (5)$$

Where  $K$  = Boltzmanns constant ( $1.38 \times 10^{-23}$  Joules/deg. Kelvin),  $T$  = Temperature in degrees Kelvin,  $B$  = Bandwidth in Hertz,  $r_d$  = dynamic resistance, and  $e$  = Electron charge ( $1.6 \times 10^{-19}$  coulombs). The dynamic resistance is inversely proportional to the direct current and decreases as the direct current increases, thereby causing the Gaussian noise voltage across the junction to decrease. Yet, if the direct current increases, the dynamic resistance decreases more quickly than the Gaussian noise current increases. As such, the Gaussian noise voltage becomes inversely related to the direct current. However, for the proposed random noise generator, the noise diode is a Zener diode with a white Gaussian distribution. The noise power density remains constant with a frequency from 0.1Hz to 10MHz and the amplitude has a Gaussian distribution. The noise must be amplified to a level where it can be accurately thresholded with no bias using a clocked comparator. The applied voltage is  $\pm 15V_{dc}$  and the current-limiting resistor is  $16K\Omega$ . The frequency range is 0.1Hz to 10MHz and the noise output is  $0.1\mu V/\sqrt{Hz}$  (min.). The noise diode breakdown voltage is 7V to 10V.

### 2.2 Amplification of Noise Source

The amplification technique [5] uses a high-gain, high-bandwidth amplifier to amplify the small ac voltage produced by a thermal or Gaussian noise source.

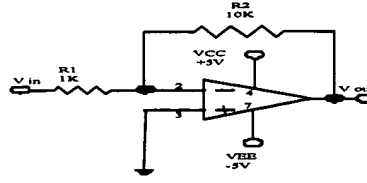


Fig. 2. Schematic Drawing of Amplifier

The noise must be amplified to a level where it can be accurately thresholded with no bias using a clocked comparator. The amplifiers operate from  $\pm 5V$  supplies.  $C_1$  and  $C_2$  are the power supply bypass capacitors.  $C_3$  helps to prevent peaking at high frequencies. This peaking results from the input capacitance of the OP Amplifier, which is driven by the relatively high impedance of the feedback resistors,  $R_1$  and  $R_2$ .

### 2.3 Sampling and filtering for gathering comparator output

When the output of a fast oscillator is sampled on the rising edge of a slower reference clock, the comparator features differential analog inputs and TTL logic outputs with an active internal pull-up and supplies a fast propagation delay for the sampling circuits. The applied voltage is  $\pm 5Vdc$  and propagation delay is 8nsec. The frequency range can be stably operated up to 100MHz. First, the sampled stream is gathered, then a filtering algorithm is used to enhance the statistical randomness. The filtering algorithm provides a stable random bit stream instead of a biased and faulted stream. Generally, since the randomness of the bit stream from the random noise generator can not be continuously guaranteed, the random noise generator guarantees the security level performance using a filtering algorithm, which resolves the problem of an unbiased, unstable random bit stream.

## 3. CHARACTERISTICS OF PROPOSED SYSTEM

### 3.1 Implemented Architecture and Environment

Basic simulation models were created for the common RNG methods to track the effects of topological design decisions and key circuit parameters on randomness. These models produced binary sequences, which were checked for randomness using accepted statistical randomness tests. Ten minutes is required to gather stable White GAUSSIAN random noise from a ZENER diode noise source. The proper amplitude for the amplification noise voltage should be about 1Volt to reduce the effect of bias. Based on equation (1), the diode current slightly fluctuates at the center of the level, which is based on the DC value. The RMS value of the Gaussian noise due to a drift current(DC) of 0.3mA is about  $1\mu A/Hz^{1/2} [ = 2 \cdot 1.6 \cdot 10^{-19} \cdot 0.3 \cdot 10^{-3} ]$ . The output waveform of the diode stage represents the spectrum density with a white noise frequency distribution and instantaneous amplitude with a Gaussian distribution. The collected AC signal, which is the output of the filter stage using HPF, without a DC signal, is applied as the noise source. The determination of the low cut-off frequency required for gathering the effective random bit stream is as follows:

$$f_c = 1/2 \cdot \pi \cdot R \cdot C \quad (6)$$

Where  $\pi = 3.14$ ,  $R$  is the resistor, and  $C$  is the capacitor. Therefore, the value of  $f_c$  is  $1/[2 \cdot 3.14 \cdot 2.4K \cdot 0.00015E-6] = 442.1KHz$ . Thus, the available frequency range is from 442KHz to 10GHz. From Figure (2), the voltage gain ( $A_v$ ) of the inverse amplifier of the noise source is as follows:

$$A_v = V_O / V_i = -R_1 / R_2 \quad (7)$$

Where  $R_1=10K$  and  $R_2=1K$ . Thus, the voltage gain ( $A_v$ ) can be amplified by a multiple of 10 of the input noise source, as presented in Figure (2).



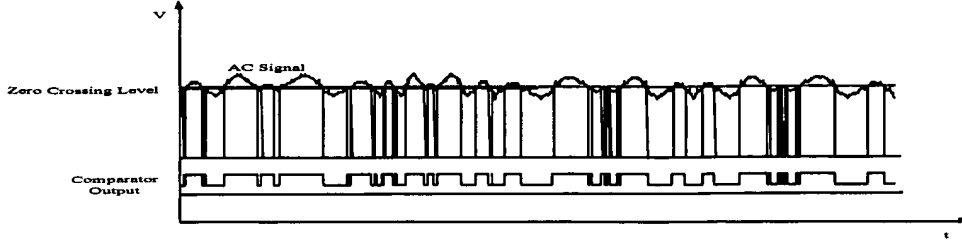


Fig.3. Comparison of Comparator Stage and Amp Stage

The comparator is decided by the zero crossing level. The variation in the voltage level of the noise source, which is based on the zero crossing point, is due to the transition of the output voltage state. The output of the comparator is sampled at the sampling rate. Determining the sampling rate for the sampler is important, because the statistical randomness of the output stream of a random bit "0/1" is dependent on the reference clock rate of the comparator and sampling rate of the sampler. The sampling rate applied to the sampler is a clock rate 1/30 slower than the reference clock rate for the comparator. As a result, the sampler collects an unbiased random bit stream.

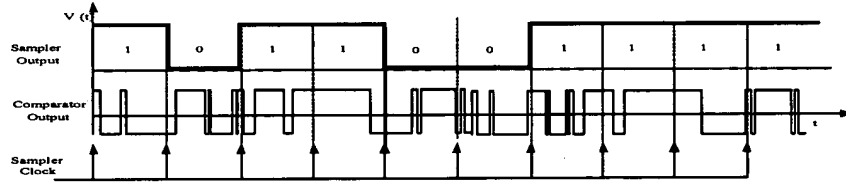


Fig.4. Output of Sampler

### 3.2 Filtering Algorithm

An filtering algorithm is applied in the next process of the output stream of the sampler to reduce the biased statistical randomness. If the optimum buffer size [64bits] and significance level [P] are established, this supports unbiased and stable randomness.

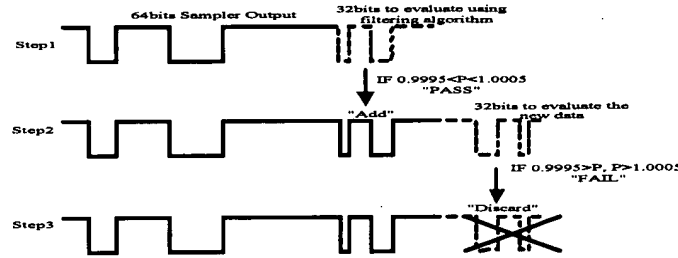


Fig. 5. Process of filtering algorithm

In the current paper, a static buffer memory of 64bits is used to buffer the "pass data" in the decision boundary and the significance level for the P value is between 0.9995 and 1.0005.

$$P = \frac{\text{the sum of number of '1' bit (Total\_Sum)}}{\text{the\_half\_value\_of\_the\_static\_length} \times \text{Total\_Length}} \quad (8)$$

When the static buffer is fixed at 64bits, the half-value of the static length is 16 bits. If the value of  $\{\sum \{\text{the number of a pattern '1' bit}\} / \text{the half-value of the static length within the total length}\}$  is included in the significance level, the decision will be "pass". In step 1, if "pass" is decided, this is added as pass

data to the buffer memory. In step 3, if “fail” is decided, this is discarded as failed data. The process is then completed when the size of the desired bit stream is gathered.

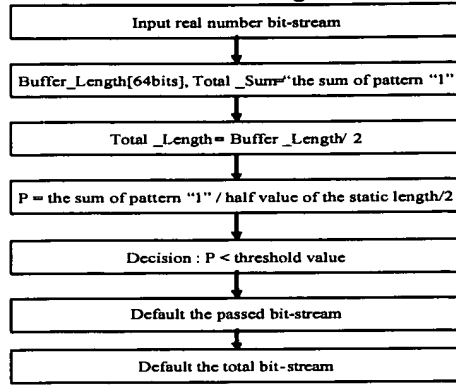


Fig. 6. Block diagram of filtering algorithm

### 3.3 Experimental Results

This section presents the results obtained from the proposed system. First, the effect of the randomness of the output random bit stream was investigated. More quantitative tests for randomness can be found in technical literature [6-7]. In Figures 8 – 11 represent various randomness tests along with their references, typical pass/fail boundaries, the measured average of 20 iteration tests based on 8MB samples, and whether the sequence passed all the trial tests. The test results were extremely positive: i.e. the proposed system passed all the trial tests. The proposed system was able to generate an 8MB data size within 7minutes. The direct line in the graph is the threshold value for making a decision. If the evaluation level goes above the threshold level, the decision will be “fail”.

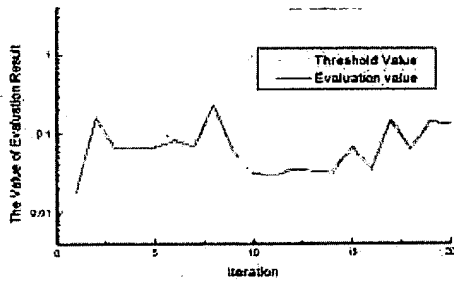


Fig. 6. Evaluation Value for Frequency Test

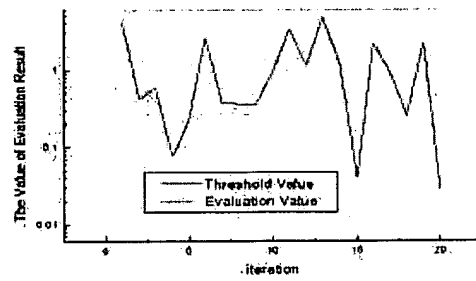


Fig. 7. Evaluation Value for Serial Test

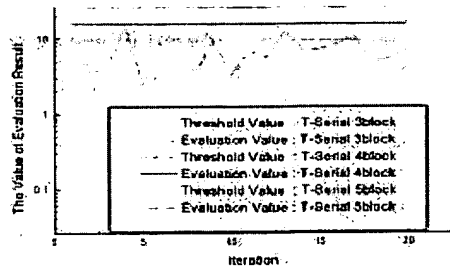


Fig. 8. Evaluation Value for T-Serial Test

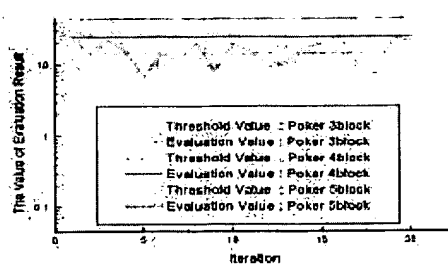


Fig. 9. Evaluation Value for Poker Test

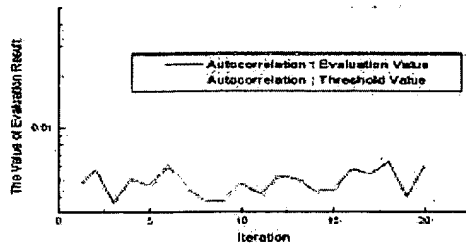


Fig. 10. Evaluation Value for Autocorrelation Test

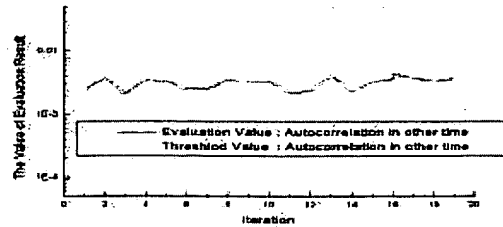


Fig. 11 Evaluation Value for Autocorrelation Test with another time

Figures 6-10 present the evaluation results for each item. Figure 11 shows a comparison of the evaluation value of a gathered bit stream with another time, demonstrating that the evaluation value was not correlated with itself or with another time. Accordingly, the graphs clearly illustrate that the evaluation value of the random bit stream was smaller than the threshold value. Although the current results only represent intuitive randomness, the proposed model is expected to be useful in a random noise generator.

#### 4. CONCLUSION

The current paper presented and tested a random noise generator using Gaussian noise. The proposed method, directly derived from results obtained from the Gaussian noise generator, is based on filtering a white noise sequence using a software filter. The Gaussian noise generator concept can be applied to any IC process where a Zener diode is available. The random noise generator is well suited for applications such as data encryption, circuit testing and measurement, and mathematical simulations. With further improvements to the design of the random noise generator components, even faster data gathering can be achieved.

#### REFERENCES

- [1] C. S. Petrie and J. A. Connelly, "A Noise-Based Random Bit Generator IC for Applications in Cryptography," Proc. ISCAS'98, June 1998.
- [2] <http://www.io.com/~ritter/RES/NOISE.HTM>.
- [3] <http://www.clark.net/pub/cme/P1363/ranno.html>.
- [4] [http://webnz.com/robert/true\\_rng.html](http://webnz.com/robert/true_rng.html).
- [5] W. Timothy Holman, J. Alvin Connelly, and Ahmad B. Dowlatabadi, "An Integrated Analog/Digital Random Noise Source," IEEE Transactions on Circuits and System I: Fundamental Theory and Applications, Vol.44, No.6, June 1997.
- [6] FIPS 140-1, "Security Requirements for Cryptographic Modules," [Federal Information Processing Standards Publication 140-1], U.S. Department of Commerce/NIST[National Technical Information Service] Springfield, Virginia, 1994. <http://csrc.nist.gov/fips/fips1401.htm> (16 Oct. 1998).
- [7] "Diehard," <http://stat.fsu.edu/~geo/diehard.html> (16 Oct. 1998).

# Lawrence Livermore National Laboratory

37°02′41″N 121°47′09″E﻿ / ﻿37.04472°N 121.78583°E﻿ / 37.04472; 121.78583 ([http://tools.wikimedia.de/~magnus/geo/geohack.php?params=37.04472\\_N\\_121.78583\\_E\\_type=landmark\\_region:US](http://tools.wikimedia.de/~magnus/geo/geohack.php?params=37.04472_N_121.78583_E_type=landmark_region:US))  
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The **Lawrence Livermore National Laboratory (LLNL)** is a United States Department of Energy (DOE) national laboratory, managed and operated by the University of California, in Livermore, California. Along with Los Alamos National Laboratory in New Mexico, it is one of the two United States laboratories whose founding mission was the design of nuclear weapons.

LLNL is self-described as "a premier research and development institution for science and technology applied to national security."<sup>[1]</sup> It is responsible for ensuring that the nation's nuclear weapons remain "safe, secure, and reliable" through application of advances in science, engineering, and technology. The laboratory also applies its special expertise and multidisciplinary capabilities to preventing the proliferation (<http://en.wiktionary.org/wiki/proliferation>) and use of weapons of mass destruction, and to bolstering homeland security. Those capabilities are also utilized in programs in non-defense areas such as basic science, energy, environmental science, and biosciences.

LLNL is home to many of the most powerful computer systems in the world, according to the TOP500 list — including Blue Gene/L, the world's fastest computer. Since 1978 the laboratory has received a total of 113 prestigious R&D 100 Awards, including seven in 2006, the most for any institution.<sup>[2]</sup> The awards are given annually by the editors of R&D Magazine (<http://www.rdmag.com/>) to the most innovative ideas of the year.

LLNL's main facility is located on a one-square-mile site in Livermore, CA. Site 300, a ten-square-mile remote explosive/experiment testing site, is situated 18 miles to the east. Lawrence Livermore has an annual budget of about \$1.6 billion and a staff of over 8,000 University of California employees, as well as 1,500 contract employees. Additionally, there are approximately 100 DOE employees stationed at the laboratory to provide federal oversight of LLNL's work for the DOE.

## Lawrence Livermore National Laboratory



|                         |  |
|-------------------------|--|
| <b>Motto</b>            | "Science in the national interest"   |
| <b>Established</b>      | 1952   |
| <b>Research Type</b>    | National security and basic science  |
| <b>Budget</b>           | \$1.6 billion/year   |
| <b>Director</b>         | George H. Miller   |
| <b>Staff</b>            | 9,600 (100) (United States Department of Energy)   |
| <b>Location</b>         | Livermore, CA  |
| <b>Campus</b>           | 398 acres  |
| <b>Operating Agency</b> | University of California   |
| <b>Website</b>          | <a href="http://www.llnl.gov">www.llnl.gov</a> ( <a href="http://www.llnl.gov/">http://www.llnl.gov/</a> ) |



Aerial view of the lab and surrounding area.

## Contents

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- 2 Non-weapons projects
- 3 Key facilities
- 4 Sponsors
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- 8 Organization
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## Origins

The main site, at the location of a former World War II Naval Training Station, was originally used to house projects of the University of California Radiation Laboratory which were too large for its location on the hills of Berkeley, California. In 1949, Edward Teller suggested to Ernest Lawrence, head of the Berkeley lab (now known as the Lawrence Berkeley National Laboratory (LBNL)), that a second weapons lab be created as "competition" with the lab which sprung up to create the first nuclear weapon, Los Alamos National Laboratory. Teller's advocacy for the lab was also in response to his frustrations with the low priority he felt his idea of a hydrogen bomb was getting at Los Alamos. In 1951, Teller formally appealed to the Atomic Energy Commission for the creation of the laboratory, and in September 1952 the lab was formally founded as the Livermore branch of the University of California Radiation Laboratory (Lawrence's lab in Berkeley). Despite Teller's original motivation, however, the hydrogen bomb was primarily designed at Los Alamos.

Thirty-two-year-old Herbert York was appointed the first director of the Lab. York set out to develop the Lab's program and created four main elements: Project Sherwood (the Magnetic Fusion Program), diagnostic weapon experiments (both for Los Alamos and Livermore), the design of thermonuclear weapons, and a basic physics program. The first two facilities were a building to house the latest electronic computer, a UNIVAC I, and a technology building with a large central bay for lifting heavy equipment.

In 1958, after the death of Ernest O. Lawrence, the lab was renamed **Lawrence Radiation Laboratory**. It would later be renamed to its current name of **Lawrence Livermore National Laboratory** in 1979.

Throughout the Cold War, Lawrence Livermore competed with Los Alamos to design the nation's nuclear arsenal, as well as perform other science and technology related tasks (some classified, some not). In the early 1990s their weapons work shifted into stockpile stewardship.

Historically the two University of California national laboratories in Berkeley and Livermore named after Ernest O. Lawrence, have had very close relationships on research projects, business operations, and staff. In fact, LLNL was not officially severed administratively from LBNL until the early 1970s. To this day, in official planning documents and records, LBNL is designated as "Site 100", LLNL as "Site 200", and LLNL's experimental testing area located near Tracy, California as "Site 300".

## Non-weapons projects

A current project is the "small, sealed, transportable, autonomous reactor" or "SSTAR". It is designed to be a "world" nuclear reactor, that can give countries with smaller or less-well-developed electricity grids a self-contained reactor that would operate for 30 years without refueling and then be retrieved - thus preventing the host nation from accessing any plutonium created as a by-product of the nuclear reaction.

Lawrence Livermore National Laboratory is a partner in the Joint Genome Institute (JGI) located in Walnut Creek, California. JGI was founded in 1997 to unite the expertise and resources in genome mapping, DNA sequencing, technology development, and information sciences pioneered at the three genome centers at UC's Lawrence Berkeley National Laboratory (LBNL) and Lawrence Livermore National Laboratory, and the Los Alamos National Laboratory (LANL).

Lawrence Livermore National Laboratory has worked out several energy technologies in the field of coal gasification, oil shale retorting, geothermal energy, advanced battery research, solar energy, and fusion energy. Main oil shale processing technologies worked out by the Lawrence Livermore National Laboratory are LLNL HRS (hot-recycled-solid), LLNL RISE and LLNL radiofrequency technologies.

LLNL has been the leader in licensing and royalty income among the Department of Energy's national laboratories. During FY 2006 the Lab's Industrial Partnerships & Commercialization Office (IPAC) reported that LLNL received \$6.4 million in licensing revenue, of which \$6.1 million was from royalties. This was the highest among the DOE funded national laboratories.

Also, during FY 2006, LLNL had 158 invention disclosures, filed 72 patent applications and received 72 patents.

Most licensing income comes from the sale of products based on Lab technologies and licensed by IPAC. LLNL's cumulative

licensing revenue for 1996 to 2006 was \$40 million - the most in the DOE sponsored national laboratory system. The bulk of the net proceeds were distributed back to the Lab's directorates, with most of the remainder going to the inventors and a smaller amount going to the institution covering some administrative costs, technology maturation and other technology transfer-related activities.

IPAC licenses LLNL technology to industry to enhance U.S. economic competitiveness in world markets, promote economic development both locally and throughout the United States, and to help improve the quality of life for all Americans.

## Key facilities

- **National Ignition Facility (NIF):** a football stadium-sized 192-beam laser facility currently under construction, providing a unique capability for investigating the physics of special nuclear materials, as well as ultimately achieve a controlled ignition and fusion burn in a laboratory setting. "Early light" was achieved at NIF in 2003, and four laser beams are now operational—meeting performance requirements for component systems and supporting experimental programs.
- **Secure and Open Computing Facilities:** the ASCI White machine, at over 10 trillion operations per second (10 teraflops), supported stockpile stewardship until it was decommissioned in 2006, and ASC Purple (100-teraflops) and BlueGene/L arrived in 2005 and were installed in the Terascale Simulation Facility and currently support stockpile stewardship.
- **Contained Firing Facility:** located at Site 300 it is a versatile hydrodynamic test facility, recently upgraded to environmentally contain explosion debris.
- **Superblock:** the most heavily fortified and guarded set of buildings in California, these modern facilities are used for special nuclear materials research, engineering testing, and storage.
- **National Atmospheric Release Advisory Center (NARAC):** uses complex 3-D computer modeling to provide atmospheric pollution plume predictions in time for emergency response to the release of radioactive or other hazardous materials.
- **Center for Accelerator Mass Spectrometry:** the most versatile system in the world for accelerator-based measurements of isotopic abundance.
- **Forensic Science Center:** has exceptional chemical and forensic analysis capabilities and expertise that supports Federal Bureau of Investigation (FBI) and law enforcement needs in the area of chemical, nuclear, biological, and high-explosives counter-terrorism.
- **Alameda County Regional Emergency Communications Center (ACRECC):** LLNL is home to the main fire and emergency medical service dispatch center for Alameda County. The state-of-the art emergency communication center is located inside a secure area of the Laboratory. ACRECC dispatches for over 41 fire stations in 6 agencies in the County. ACRECC handles more than 75,000 calls annually in the cities of Alameda, Castro Valley, Dublin, Fremont, San Leandro, San Lorenzo, Sunol, and Union City, the Parks Reserve Forces Training Area (United States Army), unincorporated areas, and both LBNL and LLNL. ACRECC also performs emergency medical dispatch and ambulance transport coordination, and coordinates Mutual Aid requests for the entire county. Funding for ACRECC is paid by each member agencies and is based on their individual usage rates. In 2003 the ACRECC dispatch center underwent a \$1.2 million renovation, adding state-of-the-art computer-aided dispatch stations, lighting, computers, and radio systems. It is currently staffed by 25 dispatchers and supervisors.

## Sponsors

LLNL's funding comes from the DOE Office of Defense Programs for nuclear weapons stockpile stewardship activities. Funds to support LLNL's national security and homeland security work also comes from the DOE Office of Defense Nuclear Nonproliferation, the Department of Homeland Security, various Department of Defense sponsors, and other federal agencies.

LLNL also receives funding to perform work for other DOE programs, principally the Offices of Science, Civilian Radioactive Waste Management, and Nuclear Energy. Non-DOE sponsors include NASA, Nuclear Regulatory Commission (NRC), National Institutes of Health, and Environmental Protection Agency, State of California agencies, and private industry.

## Computers

The first computer the laboratory possessed was a UNIVAC I, ordered in July through September 1952 and delivered in April 1953. The June 2006 release of the 27th TOP500 list of the 500 most powerful computer systems in the world, has LLNL computers in the #1 (BlueGene/L) and #3 (ASC Purple) spots. A total of 12 LLNL computer systems appeared in the June 2006 TOP500 list, tying the number at Sandia National Laboratories for the most at any one site.

On June 22, 2006, University of California researchers at LLNL announced that they had devised the world's most powerful software - a scientific application that sustained 207.3 trillion operations per second. This was the equivalent of an online game capable of handling 300 million simultaneous players. The record performance was made at LLNL on the IBM Corp's BlueGene/L, the world's fastest supercomputer, which has 131,072 processors. The record was a milestone in the evolution of predictive science, a field in which researchers use supercomputers to answer questions about such subjects as; materials science simulations, global warming, and reactions to natural disasters.

Over the years other computers were installed, including:

- 2 IBM 701s
- 4 IBM 704s
- 4 IBM 709s
- 4 IBM 7090s
- 1 UNIVAC LARC
- 5 IBM 7094s
- 1 IBM 7030 (Stretch)
- 1 CDC 1604
- 2 CDC 3600s
- 4 CDC 6600s
- 5 CDC 7600s
- 2 CDC STAR 100s
- 4 Cray-1s
- 5 Cray X-MPs
- 3 Cray-2s
- 2 Cray Y-MP8s
- 1 BBN Butterfly
- 1 Cray C90
- 1 Meiko CS-2
- 1 Cray T3D
- IBM ASCI Blue Pacific
- IBM ASCI White
- ASC Purple
- IBM Blue Gene/L.
- Peloton.

## Computer Software

A great deal of software has been written by LLNL personell to operate, monitor, and manage the computer systems at LLNL, including operating system extension such as CHAOS (Linux Clustering), resource management packages such as SLURM, and others<sup>[3]</sup> The requirement for lab programmers to write the software is due to the unique, one-of-a-kind nature of the systems — this had prevented commercial off-the-shelf (COTS) software from being available. It wasn't until the Peloton<sup>[4]</sup> systems procurements in late 2006 that a commercial resource management package, Moab, was to be used to manage the clusters purchased under the RFP.

## Plutonium research and storage

According to published reports the lab has about 880 pounds of plutonium and is allowed to have up to about 3,080 pounds. However, it is not allowed to have actual nuclear weapons or nuclear explosive devices at its sites. Plutonium at the lab is stored in a fortified research facility guarded by a large force of heavily armed and specially trained University of California security police officers.

At Livermore and at two facilities in Nevada, the lab uses plutonium for nuclear weapons research. It conducts experiments to learn how plutonium performs as it ages; how it behaves under high pressure, such as with the impact of high explosives; and how to dismantle nuclear weapons safely, without causing contamination.

In early 2006 the United States Department of Energy announced plans to move all the plutonium from Lawrence Livermore Laboratory by 2014, though transfers of the material could start sooner. By 2022, all U.S. work involving plutonium would be consolidated at a single new facility whose location has not been determined.

## Directors

The LLNL Director is appointed by the Regents of the University of California and reports to the President of the University of California. Supporting the LLNL Director are two deputies - one for Science & Technology and one for Operations, a Chief of Staff, and the Laboratory Executive Officer.

Also reporting to the Director are several key functional managers - Safeguards & Security, Audit & Oversight, Chief Financial Officer, and Laboratory Counsel.

- Herbert York (1952–1958)
- Edward Teller (1958–1960)
- Harold Brown (1960–1961)
- John S. Foster (1961–1965)
- Michael M. May (1965–1971)
- Roger E. Batzel (1971–1988)
- John H. Nuckolls (1988–1994)
- C. Bruce Tarter (1994–2002)
- Michael R. Anastasio (2002–2006)
- George H. Miller (2006–present [interim director])

## Organization

- Director
- Deputy Director for Science & Technology
- Deputy Director for Operations
- Associate Directors
  - Administration & Human Resources
  - Chemistry, Materials, and Life Science
  - Computation
  - Defense & Nuclear Technologies
  - Energy & Environment
  - Engineering
  - Laboratory Services
  - National Ignition Facility Programs
  - Nonproliferation, Homeland and International Security
  - Physics & Advanced Technologies
  - Safety & Environmental Protection

## Footnotes




1. ^ From LLNL's Official website "Missions & Programs" LLNL's Mission (<http://www.llnl.gov/llnl/missions/>)
2. ^ As noted in the Official LLNL Press Release of 10 Jul 2006 R&D 100 at LLNL ([http://www.llnl.gov/pao/news/news\\_releases/2006/NR-06-07-01.html](http://www.llnl.gov/pao/news/news_releases/2006/NR-06-07-01.html))
3. ^ Linux at Livermore (<http://www.llnl.gov/linux/projects.html>). Retrieved on 2007-02-28.
4. ^ Peloton Capability Cluster (<http://www.llnl.gov/linux/peloton/rfp/>). Retrieved on 2007-02-28.

## References

- *Nuclear Rites: A Weapons Laboratory at the End of the Cold War*, by Hugh Gusterson, University of California Press, Berkeley, 1996 (ISBN 0-520-21373-4)

## External links and sources

- Lawrence Livermore National Laboratory (<http://www.llnl.gov/>) (official website)
- Laboratory History ([http://www.llnl.gov/50th\\_anniv/history.htm](http://www.llnl.gov/50th_anniv/history.htm)) (official website)
- LLNL Industrial Partnerships and Commercialization (IPAC) (<http://www.llnl.gov/IPandC>) (official website)
- University of California Office of Laboratory Management (<http://labs.ucop.edu/>) (official website)
- Society of Professionals, Scientists and Engineers (<http://www.spse.org/>) (Union representing UC Scientists and Engineers at LLNL)
- Annotated bibliography for Livermore from the Alsos Digital Library for Nuclear Issues (<http://alsos.wlu.edu/qsearch.aspx?browse=places/Livermore,+California>)
- Maps and aerial photos ([http://tools.wikimedia.de/~magnus/geo/geohack.php?params=37.686024\\_N\\_-121.709547\\_E\\_type:landmark\\_region:US](http://tools.wikimedia.de/~magnus/geo/geohack.php?params=37.686024_N_-121.709547_E_type:landmark_region:US))
  - Street map from Google Maps (<http://maps.google.com/maps?ll=37.686024,-121.709547&q=37.686024,-121.709547&spn=0.015,0.025>) or Yahoo! Maps ([http://maps.yahoo.com/maps\\_result?lat=37.686024&lon=-121.709547&mag=2](http://maps.yahoo.com/maps_result?lat=37.686024&lon=-121.709547&mag=2))
  - Topographic map from TopoZone (<http://topozone.com/map.asp?lat=37.686024&lon=-121.709547&s=24&size=m&datum=nad83>)
  - Aerial image or topographic map from TerraServer-USA (<http://terraserver-usa.com/image.aspx?s=11&lon=-121.709547&lat=37.686024&w=2>)
  - Satellite image from Google Maps (<http://maps.google.com/maps?ll=37.686024,-121.709547&q=37.686024,-121.709547&spn=0.015,0.025&t=h>) or Microsoft Virtual Earth (<http://virtualearth.msn.com/default.aspx?cp=37.686024|-121.709547&style=h&lvl=15&v=1>)

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|---|--------------------------|---|
|  | <i>Fiat Lux</i>          | <b>University of California</b><br>Oakland (Home Office)  |
|   | <b>Campuses</b>          | Berkeley • Davis • Hastings • Irvine • Los Angeles • Merced • Riverside • San Diego • San Francisco • Santa Barbara • Santa Cruz  |
|   | <b>UC Medical System</b> | San Francisco • Los Angeles • San Diego • Davis • Irvine  |
|   | <b>Research Stations</b> | Lawrence Berkeley National Laboratory • <b>Lawrence Livermore National Laboratory</b> • Los Alamos National Laboratory (affiliated) • Lick Observatory • Keck Observatory |

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Categories: 1952 establishments | Alameda County, California | Nuclear research centers | Nuclear weapons infrastructure of the United States | Research institutions in the San Francisco Bay Area | Livermore, California | United States Department of Energy National Laboratories | University of California | Supercomputer sites

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Lawrence Livermore National Laboratory (LLNL) is a premier applied science laboratory that is part of the National Nuclear Security Administration (NNSA) within the Department of Energy (DOE). LLNL has been managed since its inception in 1952 by the University of California for the U.S. government.

As a national security laboratory, LLNL is responsible for ensuring that the nation's nuclear weapons remain safe, secure, and reliable through application of advances in science and engineering. With its special capabilities, the Laboratory also meets other pressing national security needs, which include countering the proliferation of weapons of mass destruction and strengthening homeland security against the terrorist use of such weapons.

Our breakthrough advances are made possible by an extraordinary technical staff and investments in research facilities that provide LLNL wide ranging capabilities. The Laboratory is an international leader in many areas of science and technology central to our national security mission.



With our broadly based capabilities and leadership in mission-focused areas of science and engineering, the Laboratory is able to also make major advances to meet other national needs. LLNL pursues major research programs in energy and environment, bioscience and biotechnology, and basic science and advanced technology.



The Laboratory is able to attract a superb workforce because of its exciting missions and opportunities to pursue leading-edge research as part of multidisciplinary teams. This keeps the Laboratory at the forefront of technical capabilities necessary for our national security mission and ready to effectively respond to evolving changes in national priorities and surprises.

Lawrence Livermore has an annual budget of about \$1.6 billion and a staff of over 8,000 employees. It is home to over 3,500 scientists, engineers, and technicians together with professionals in many other disciplines to keep the Laboratory running in a safe, secure and efficient manner.

## Computation Directorate

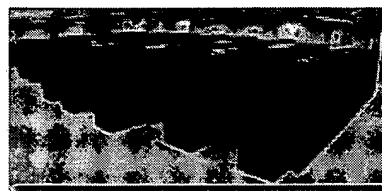
- Computation Directorate Website
- Associate Director's Bio



Since 1952, Laboratory scientists and engineers have relied on the most advanced simulation environments for science in the national interest.

Computation offers computing capacity and capability in support of the nation's Stockpile Stewardship Program. This makes Computation a key partner in the Advanced Simulation and Computing (ASC) program historically known as ASCI. Computation also provides unclassified computing capacity and capability in support of Multiprogrammatic & Institutional Computing (M&IC).

According to recent TOP500 lists, Computation operates some of the world's fastest supercomputers: BlueGene/L, a cooperative project to design and build a computer architecture capable of scaling to hundreds of teraflops (TF); ASC Purple, a genuinely huge machine based on symmetric shared-memory multiprocessors containing more than 12,000 next-generation IBM Power5 microprocessors and capable of 100 TF; and Thunder (right), a highly integrated, well-balanced capability compute resource with 1,024 nodes and a theoretical system peak performance of 22.9 TF.



# June 2006

## Overview

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The 27th TOP500 List was introduced during the [International Supercomputer Conference \(ISC2006\)](#) in Dresden, Germany.



The No. 1 position was again claimed by the BlueGene/L System, a joint development of IBM and DOE's National Nuclear Security Administration (NNSA) and installed at DOE's Lawrence Livermore National Laboratory in Livermore, Calif. BlueGene/L also occupied the No. 1 position on the last three TOP500 lists. It has reached a Linpack benchmark performance of 280.6 TFlop/s ("teraflops" or trillions of calculations per second) and still remains the only system ever to exceed the level of 100 TFlop/s. This system is expected to remain the No. 1 Supercomputer in the world for the next few editions of the TOP500 list.

Even as processor frequencies seem to stall the performance improvements of full systems seen at the very high end of scientific computing shows no sign of slowing down. This time the last 158 systems on the list in June 2005 are too small to be included any longer, which represents a lower than average turn-over rate after two record breaking rates in the last lists. However, the growth of average performance remains stable and ahead of Moore's Law.

## Dr. Borko Furht's Publications

1. B. Furht, E. Muharemagic, and D. Socek, "**Multimedia Encryption and Watermarking**," Springer, Boston, MA, 2005.
2. B. Furht and D. Kirovski, "**Multimedia Security Handbook**," CRC Press, Boca Raton, Florida, 2005.
3. Borko Furht and Oge Marques, "**Handbook of Video Databases: Design and Applications**," CRC Press, 2004.
4. B. Furht and M. Ilyas, "**Wireless Internet Handbook: Technologies, Standards, and Applications**," CRC Press, Boca Raton, Florida, 2003.
5. Oge Marques and Borko Furht, "**Content-Based Image and Video Retrieval**," Kluwer Academic Publishers, Norwell, MA, 2002.
6. B. Furht, "**Application Service Providers – Current Status and Future Trends**," International Engineering Consortium, Chicago, IL, 2001.
7. B. Furht, Author and Editor-in-Chief, "**Handbook of Internet Computing**," CRC Press, Boca Raton, Florida, 2000.
8. B. Furht, "**The Future of Unified Messaging**," International Engineering Consortium, Chicago, IL, 2000.
9. B. Furht, Editor-in-Chief, "**Handbook of Internet and Multimedia Systems and Applications**," CRC Press and IEEE Press, 1999.
10. B. Furht, Editor-in-Chief, "**Handbook of Multimedia Computing**," CRC Press, Boca Raton, Florida, 1999.
11. B. Furht, "**Multimedia Technologies and Applications for the 21st Century**," Kluwer Academic Publishers, Norwell, MA, 1998.
12. B. Furht, J. Greenberg, and R. Westwater, "**Motion Estimation Techniques for Video Compression**," Kluwer Academic Publishers, Norwell, MA, 1996.
13. R. Westwater and B. Furht, "**Real-Time Video Compression: Techniques and Algorithms**," Kluwer Academic Publishers, Norwell, MA, 1996.
14. B. Furht, editor, "**Multimedia Systems and Techniques**," Kluwer Academic Publisher, Norwell, MA, 1996.
15. B. Furht, editor, "**Multimedia Tools and Applications**," Kluwer Academic Publisher, Norwell, MA, 1996.
16. B. Furht and M. Milenkovic, "**A Guided Tour of Multimedia Systems and Applications**," Tutorial, IEEE Computer Society Press, 1995.
17. B. Furht, S. Smoliar, and HJ. Zhang, "**Video and Image Processing in Multimedia Systems**," Kluwer Academic Publishers, Norwell, MA, 1995.
18. B. Furht, D. Grostick, D. Gluch, G. Rabbat, J. Parker, and M. McRoberts, "**Real-Time UNIX Systems: Design and Applications Guide**," Kluwer Academic Publishers, Norwell, MA, 1991, Translated in Japanese: Nikkei Business Publications, Tokyo, 1991.
19. B. Furht and G. Rabbat, "**Handbook on Design and Applications of MODCOMP Computer Systems**," Modcomp Press, Fort Lauderdale, Florida, 1989.
20. D.D. Gajski, V. Milutinovic, H.J. Siegel, and B. Furht, "**Computer Architecture**," IEEE Tutorial, IEEE Computer Society Press, 1987.
21. B. Furht and H. Parikh, "**Microprocessor Interfacing and Communications with the Intel SDK-85**," Prentice-Hall, Englewood Cliffs, New Jersey, 1986.



## Dr. Borko Furht's Publications

22. B. Furht, "**The Application of Mathematical Models in Hot Strip Mill Computer Control**," Monograph, Institute Boris Kidric-Vinca, Belgrade, Yugoslavia, 1977.
23. M. Carapic, Z. Pendic, B. Furht, and D. Veselinovic, "**The Design of Computer Information Systems**," Technical Book, Belgrade, Yugoslavia, 1974.

Top

### **Journal Papers**

1. H. Kalva, B. Petljanski, and B. Furht, "Complexity Reduction Tools for MPEG-2 to H.264 Video Transcoding," WSEAS Transactions on Information Science and Applications, Vol. 2, Issue 3, March 2005, pp. 295-300.
2. O. Marques and B. Furht, "MUSE: A Content-Based Image Search and Retrieval Using Relevance Feedback," International Journal of Multimedia Tools and Applications, Vol. 17, No. 1, May 2002, pp. 21-50.
3. B. Furht, J. Sheen, and Z. Aganovic, "Delivering Document Management Systems Through the ASP Approach," Annual Review of Communications, Vol. 54, International Engineering Consortium, Chicago, IL, Fall 2001.
4. B. Furht, "Security Issues in the ASP Systems," Annual Review of Communications, International Engineering Consortium, Vol. 54, Chicago, IL, Fall 2001.
5. B. Furht, R. Westwater, and J. Ice, "Multimedia Broadcasting Over the Internet: Part II – Video Compression," IEEE Multimedia, Vol. 6, No. 1, 1999.
6. B. Furht, R. Westwater, and J. Ice, "Video Broadcasting on the Internet," 1999 Annual Review of Communications, Vol. 52, International Engineering Consortium, Chicago, IL, October 1999.
7. B. Furht, R. Westwater, and J. Ice, "Multimedia Broadcasting Over the Internet: Part I," IEEE Multimedia, Vol. 5, No. 4, 1998.
8. B. Furht, R. Westwater, and J. Ice, "A New Technique for Multimedia Broadcasting on the Internet," Journal of Computing and Information Technology, Special Issue on Emerging Technologies, 1998.
9. B. Furht, "Architecture and Performance Evaluation of the Mirror Memory Microprocessor," Computer Architecture Newsletter, March 1997, pp. 59-67.
10. R. Westwater and B. Furht, "A XYZ Algorithm for Real-Time Compression of Full-Motion Video," Real-Time Imaging Journal, Special Issue on Image and Video Processing in Multimedia Systems, Vol. 2, No. 1, February 1996, pp. 19-34.
11. B. Furht, "Where Are Information Superhighway Headed?" ACM Computing Surveys, invited paper, Vol. 27, No. 4, December 1995, pp. 552-556.
12. B. Furht, "A Survey of Multimedia Compression Techniques and Standards. Part II: Video Compression," Real-Time Imaging Journal, Vol. 1, No. 5, December 1995.
13. B. Furht, D. Kalra, F. Kitson, A.A. Rodriguez, and W.E. Wall, "Design Issues for Interactive Television Systems," IEEE Computer, Vol. 28, No. 5, May 1995, pp. 25-39.
14. B. Furht, "A Survey of Multimedia Compression Techniques and Standards. Part I: JPEG Standard," Real-Time Imaging Journal, Vol. 1, No. 1, April 1995, pp. 49-67.
15. B. Furht, "Are Distributed Multimedia Systems Real-Time?" International Journal of Mini and Microcomputers, Vol. 17, No. 2, 1995, pp. 71-76.

### Dr. Borko Furht's Publications

16. B. Furht, "Multimedia Systems: An Overview", IEEE MultiMedia, Vol. 1, No. 1, Spring 1994, pp. 47-59.
17. B. Furht, "Parallel Computing: Glory and Collapse", IEEE Computer, Vol. 27, No. 11, November 1994, pp. 74-75.
18. B. Furht and W. Halang, "A Survey of Real-Time Computing Systems", International Journal of Mini and Microcomputers, Vol. 16, No. 3, 1994, pp. 141-155.
19. B. Furht, "Real-Time Workstation Supports Both Development and Control", Computer Technology Review, Winter 1991, pp. 12-14.
20. B. Furht, "Suiting up RISC for Real-Time", Computer Design, September 1991, pp. 81.
21. P. Matthews and B. Furht, "Evaluating Real-Time UNIX", Embedded Systems Programming, Vol. 4, No. 7, July 1991, pp. 28-36.
22. P. Matthews and B. Furht, "Is a True Real-Time UNIX Finally Emerging?" Computer Technology News, June 1991, pp. 8.
23. D. Grostick, D.P. Gluch, and B. Furht, "REAL/IX: A Real-Time UNIX Operating System", Nuclear Instruments and Methods, North Holland, Vol. A293, 1990, pp. 271-275.
24. M. Hellstrom, J. Howard, M. Marschke, J. Wahlig, and B. Furht, "REAL/IX - A Unique Marriage Between UNIX and MAX 32 Operating Systems", International Journal of Mini and Microcomputers, Vol. 12, No. 2, 1990, pp. 42-53.
25. S. Geffin and B. Furht, "A Dataflow Multiprocessor System for Robot Arm Control", International Journal of Robotics Research, The MIT Press, Vol. 9, No. 3, June 1990, pp. 93-103.
26. B. Furht, J. Parker, D. Gluch, and D. Grostick, "Performance of REAL/IX - Fully Preemptive Real-Time UNIX", ACM Operating Systems Review, Vol. 23, No. 4, October 1989, pp. 45-52.
27. D. Gluch and B. Furht, "Fault Tolerance Strategies for High-Performance Real-Time Computers", International Journal of Mini and Microcomputers, Vol. 11, No. 2, 1989, pp. 24-30.
28. B. Furht and P.S. Liu, "An Advanced Laboratory for Microprocessor Interfacing and Communication", IEEE Transactions on Education, Vol. 32, No. 2, May 1989, pp. 124-128.
29. S. Geffin and B. Furht, "Transputer-Based Dataflow Multiprocessor for Robot Arm Control", Microprocessors and Microsystems, Vol. 13, No. 3, April 1989, pp. 219-226.
30. B. Furht, "A Contribution to Classification and Evaluation of Structures for Parallel Computers", Journal of Microprocessing and Microprogramming, March 1989, pp. 203-208.
31. G. Rabbat, B. Furht, and R. Kibler, "Three-Dimensional Computer Performance", IEEE Computer, Vol. 21, No. 7, July 1988, pp. 59-60.
32. B. Furht and A. Perez, "An Adaptive Real-Time ECG Compression Algorithm with Variable Threshold", IEEE Transactions on Biomedical Engineering, Vol. 35, No. 6, June 1988, pp. 489-494.
33. G. Rabbat, B. Furht, and R. Kibler, "Three-Dimensional Computers and Measuring Their Performance", ACM Computer Architecture News, Vol. 16, No. 3, June 1988, pp. 9-16.
34. B. Furht, H.A. Aboalsamh, W.H. Chia, and Y.N. Lai, "Multiple Register Window File for LISP-Oriented RISC Architectures", Microprocessors and Microsystems, Vol. 12, No. 4, May 1988, pp. 187-195.

## **Dr. Borko Furht's Publications**

35. B. Furht, "A RISC Architecture with Two-Size Overlapping Register Windows", IEEE Micro, Vol. 8, No. 4, April 1988, pp. 67-80.
36. B. Furht, "A Definition of Complex Instruction Set Computer (CISC) Architectures", IEEE Computer, Vol. 20, No. 5, May 1987, pp. 108.
37. B. Furht and V. Milutinovic, "A Survey of Microprocessor Architectures for Memory Management", IEEE Computer, Vol. 20, No. 3, March 1987, pp. 48-67.
38. B. Furht, M. Georgiu, and S. Cadambi, "Knowledge-Based System for Student Advising", IEEE Technical Comm. on Computer Education, Vol. 4, No. 2, Fall 1987.
39. S. Geffin, T. Burges, and B. Furht, "The Expert System for Career Planning: ACES", Journal of Microcomputer Applications, Vol. 6, No. 3, 1987, pp. 71-77.
40. B. Furht, "Evaluation and Selection of 16-Bit Microprocessors", International Journal of Mini and Microcomputers, Vol. 8, No. 1, January 1986, pp. 14-25.
41. V. Milutinovic, W. Venners, V. Egle, and B. Furht, "A Test Package for Bit-Slice and Standard-Cell Microprocessor Design", International Journal of Mini and Microcomputers, Vol. 7, No. 3, 1985, pp. 60-66.
42. B. Furht and P. Lee, "Efficient Software Driver for 9511 Arithmetic Processor Implementation", IEEE Micro, Vol. 4, No. 3, June 1984, pp. 7-19.
43. B. Furht, "Software Engineering in Microprocessor's Environment", International Journal of Mini and Microcomputers, Vol. 4, No. 2, April 1982, pp. 33-39.
44. B. Furht, "The Application of the RMX/80 in Multimicroprocessor System for Digital Signal Processing", Microprocessing and Microprogramming, Vol. 9, No. 1, January 1982, pp. 7-15.
45. B. Furht and D. Petkovic, "A Procedure for Multimicroprocessor System Testing During Development", Microprocessors and Microsystems, Vol. 5, No. 7, September 1981, pp. 313-317.

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## **Selected Conference Papers (1990-present; For all papers click on Resume)**

1. P. Sanigepalli, H. Kalva, and B. Furht, "An Improved Video Codec Supporting Error Resilience and Resource Adaptation," Proceedings of the International Conference on Consumer Electronics, January 2005.
2. P. Sanigepalli, H. Kalva, and B. Furht, "An Efficient Application of Video Error Resilience Techniques in MBMS Systems," Workshop on Wireless Multimedia, Proceedings of the IEEE Int. Symposium on Multimedia Software Engineering, December 2004.
3. A. Asaduzzaman, I. Mahgoub, P. Sanigepalli, H. Kalva, R. Shankar, and B. Furht, "Cache Optimization for Mobile Devices Running Multimedia Applications," Workshop on Wireless Multimedia, Proceedings of the IEEE Int. Symposium on Multimedia Software Engineering, December 2004.
4. J.H. Greenberg, D. Dankel, and B. Furht, "A Content Oriented Architecture for Consumer-to-Business E-Commerce," Proceedings of the 6th Int. Conference on Enterprise Information Systems, Porto, Portugal, April 2004.



## Dr. Borko Furht's Publications

5. X. Li and B. Furht, "An Approach to Image and Video Compression using Three-Dimensional DCT," Proceedings of the Visual 2003 Conference, Miami, Florida, September 2003.
6. B. Furht, K. Gustafson, H. Huang, and O. Marques, "An Adaptive Three-Dimensional DCT Compression Based on Motion Analysis," ACM Symposium on Applied Computing (SAC 2003), March 9-12, 2003, Melbourne, Florida.
7. X. Li, S.-C. Chen, M.-L. Shyu, and B. Furht, "Image Retrieval by Color, Texture, and Spatial Information," Proceedings of the 8th International Conference on Distributed Multimedia Systems (DMS'2002), San Francisco, September 2002.
8. F. M. Costa, O. Marques, and B. Furht, "Improving the Performance of Content-Based Image Retrieval Systems with Color Image Processing Tools," IASTED International Conference on Signal and Image Processing (SIP 2002), Kauai, Hawaii. August 2002.
9. O. Marques, and B. Furht, "Combining Clustering and Relevance Feedback Techniques in Content-Based Image Retrieval", IASTED International Conference on Internet and Multimedia Systems and Applications (IMSA2002), Kauai, Hawaii. August 2002.
10. X. Li, S.-C. Chen, M.-L. Chyu, and B. Furht, "A Novel Hierarchical Approach for Image Retrieval Using Color and Spatial Information," International Symposium on Information Systems and Engineering (ISE'2002), San Diego, California, July 2002.
11. X. Li, S.-C. Chen, M.-L. Chyu, and B. Furht, "An Effective Content-Based Visual Image Retrieval System," IEEE Compsac, August 2002.
12. B. Furht, J. Shin, and Z. Aganovic, "Internet-Based Delivery and Deployment of Document Management Systems," Proc. of the 34th IEEE Int. Hawaii Conference on System Sciences, January 2001.
13. O. Marques, F. Costa, and B. Furht, "Content-Based Image Search and Retrieval Using Relevance Feedback," Proc. of the IASTED Int. Conference on Internet and Multimedia Systems and Applications, Las Vegas, Nevada, November 2000.
14. B. Furht, C. Phoenix, J. Yin, and Z. Aganovic, "An Innovative Architecture for Application Service Providers," Proc. of the 33th IEEE Int. Hawaii Conference on System Sciences, January 2000.
15. O. Marques and B. Furht, "Issues in Designing Video Databases," Third Int. Conference on Internet and Multimedia Systems and Applications," Nassau, Bahamas, October 1999.
16. X. Li and B. Furht, "Design of Digital Libraries," Third Int. Conference on Internet and Multimedia Systems and Applications," Nassau, Bahamas, October 1999.
17. B. Furht, R. Westwater, and J. Ice, "A New Approach for Radio and Television Broadcasting Over the Internet," Proceedings of IEEE Conference on Multimedia Systems, Florence, Italy, June 1999.
18. B. Furht, Y. Weng, and J. Celi, "Interactive Progressive Encoding System for Transmission of Complex Images," Proc. of SPIE Symposium on Multimedia Storage and Archiving Systems, Boston, MA, November 1998.
19. B. Furht and P. Saksobhavit, "A Fast Content-Based Video and Image Retrieval Technique Over Communication Channels," Proc. of SPIE Symposium on Multimedia Storage and Archiving Systems, Boston, MA, November 1998.
20. B. Furht, R. Westwater, and J. Ice, "An Innovative Technique for Multimedia Broadcasting on the Internet", Proc. of the IEEE Conference on Software in Telecommunications and Computer Networks SoftCOM'98, Split, October 1998.

## Dr. Borko Furht's Publications

21. B. Furht, "Processor Architectures for Multimedia: A Survey", invited paper, Proceedings of Multimedia Modeling Conference, World Scientific, Singapore, November 1997, pp. 89-109.
22. B. Furht, "Multimedia Applications on the Internet", Proceedings of the International Engineering Consortium, Chicago, IL, October 1997, also the chapter in the book "The Internet and Telecommunications: Architectures, Technologies, and Business Development", 1998.
23. R. Westwater and B. Furht, "Three-Dimensional DCT Video Compression Technique Based on Adaptive Quantizers", Second IEEE Int. Conference on Engineering of Complex Computer Systems, Montreal, Canada, October 1996.
24. B. Furht, "Interactive Television Systems", Workshop on Multimedia Applications, ACM CSE/SAC Conference, Philadelphia, PA, February 1996.
25. H. Kalva and B. Furht, "Techniques for Improving the Capacity of Video-On-Demand Systems", 29th Hawaii Int. Conference on System Sciences, Wailea, Hawaii, January 1996.
26. R. Westwater and B. Furht, "The Design of an Object-Oriented Multimedia Kernel, Proc. of the IASTED/ISMM Conference on Distributed Multimedia Systems and Applications, Honolulu, Hawaii, August 1994, pp. 176-179.
27. L. Ehley, B. Furht, and M. Ilyas, "Evaluation of Multimedia Synchronization Techniques", Proc. of the IEEE Conference on Multimedia Computing and Systems, Boston, MA, May 1994.
28. P. Monnes and B. Furht, "Parallel JPEG Compression Algorithms", Proc. of the IEEE Southeastcon, Miami, Florida, April 1994. pp. 375-379.
29. B. Furht, "Real-Time Issues in Distributed Multimedia Systems", Proc. of Second Workshop on Parallel and Distributed Real-Time Systems, Cancun, Mexico, April 1994, pp. 88-97.
30. B. Furht, "Real-Time Computer Systems: Current and Future Trends", invited plenary paper, Proceedings of the First IEEE Workshop on Real-Time Applications, New York, May 1993, pp. 1-6.
31. B. Furht, "The Design of a Real-Time System for Simulators and Trainers", Proceedings of the First IEEE Workshop on Real-Time Applications, New York, May 1993, pp. 18-24.
32. B. Furht, "Performance Evaluation of REAL/IX, a Real-Time UNIX Operating System", Proceedings of the Tenth IEEE Workshop on Real-Time Operating Systems and Software, New York, May 1993.
33. B. Furht, "A Reconfigurable Real-Time System for Parallel Processing", Proceedings of the IEEE Workshop on Parallel and Distributed Real-Time Systems, Newport Beach, CA, April 1993, pp. 159-167.
34. B. Furht, "The Reality of a Real-Time UNIX Operating System", Proceedings of the NATO Advanced Study Institute on Real-Time Computing, Sent Marteen, October 1992.
35. B. Furht, "The Design of a RISC-Based Real-Time Multiprocessor System for Real-Time Applications", Proceedings of the RealTime92 Symposium, Stuttgart, Germany, June 1992.
36. B. Furht, "Designing RISC-Based Real-Time Multiprocessors", Proceedings of the First International Conference on the Design of RISC-Based Systems RISC'92, San Jose, CA, February 1992.

## **Dr. Borko Furht's Publications**

37. B. Furht, "Choosing a RISC Processor for Real-Time Applications", Proceedings of the First International Conference on the Design of RISC-Based Systems RISC'92, San Jose, CA, February 1992.
38. B. Furht and R. Luken, "The Space Shuttle Launch Computer Control System at NASA Kennedy Space Center", Proceedings of Euromicro 91 Workshop on Real-Time Systems, Paris, France, June 1991, pp. 184-192.
39. B. Furht, D. Gluch, J. Parker, P. Matthews, and D. Joseph, "The Real/Star 2000: A High-Performance Multiprocessor Computer for Telemetry Applications", Proceedings of the 1991 International Telemetering Conference, Las Vegas, Nevada, November 1991.
40. B. Furht et al. "A Tool for Performance Evaluation of Real-Time UNIX Operating Systems", Proceedings of the 1991 International Telemetering Conference, Las Vegas, Nevada, November 1991.
41. B. Furht, D. Joseph, D. Gluch, and J. Parker, "Open Systems for Time-Critical Applications", Proceedings of the 1990 International Telemetering Conference, Las Vegas, Nevada, October 1990.
42. B. Furht, D. Gluch, and D. Joseph, "Performance Measurements of Real-Time Computer Systems, Proceedings of the 1990 International Telemetering Conference, Las Vegas, Nevada, October 1990.
43. B. Furht, D. Grostick, D. Gluch, J. Parker, and W. Pastucha, "Issues in the Design of an Industry Standard Operating System for Time-Critical Applications", Proceedings of the RealTime90 Symposium, Stuttgart, Germany, May 1990.
44. D. Gluch, B. Furht, et al., "A Reconfigurable Real-Time RISC Computer System", Proceedings of the IEEE International Conference on Databases, Parallel Architectures, and their Applications, Miami Beach, Florida, March 1990.

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## **Selected Book Chapters and Other Publications (1990-present; For all publications click on [Resume](#))**

1. B. Furht, D. Socek, and A.M. Eskicioglu, "Fundamentals of Multimedia Encryption Techniques," a chapter in Multimedia Security Handbook, CRC Press, 2005.
2. E. Muharemagic and B. Furht, "A Survey of Multimedia Watermarking Techniques," a chapter in Multimedia Security Handbook, CRC Press, 2005.
3. B. Furht, R. Westwater, and J. Ice, "Multimedia Broadcasting Techniques: Present Approaches and New Trends," a chapter in Intelligent Virtual World, T.K. Shih and P.P. Wang, Eds., World Scientific Publishing Co., Singapore, 2004.
4. B. Furht and D. Socek, "A Survey of Multimedia Security," in Comprehensive Report on Information Security, International Engineering Consortium, Chicago, IL, 2004.
5. E. Muharemagic and B. Furht, "Multimedia Security: Watermarking Techniques," in Comprehensive Report on Information Security, International Engineering Consortium, Chicago, IL, 2004.
6. O. Marques and B. Furht, "Introduction to Video Databases," a chapter in the "Handbook of Video Databases," CRC Press, Boca Raton, Florida, 2004.
7. B. Furht and O. Marques, "Interactive Multimedia on the Web", a chapter in The Internet Encyclopedia, Editor-in-Chief: Hossein Bidgoli, Wiley, 2004.

### Dr. Borko Furht's Publications

8. B. Furht and M. Ilyas, "Fundamentals of Wireless Internet," a chapter in the book "Handbook of Wireless Internet," CRC Press, Boca Raton, Florida, 2003.
9. B. Furht, "Multimedia Broadcasting Techniques: Present Approaches and New Trends," a chapter in the book "Intelligent Virtual World," edited by T.K. Shih, WSP, Singapore, 2002.
10. O. Marques and B. Furht, "Content-Based Visual Information Retrieval," a chapter in the book "Distributed Multimedia Databases: Techniques and Applications," edited by T.K. Shih, Idea Group Publishing, Hershey, PA, 2001.
11. B. Furht, "Internet Architectures," a chapter in the "Handbook of Computer Engineering," edited by V. Oklobdjija, CRC Press, Boca Raton, Florida, 2001.
12. C. Law and B. Furht, "The MPEG-4 Standard for Internet-based Multimedia Applications," a chapter in the "Handbook of Internet Computing", CRC Press, Boca Raton, FL, 2000.
13. O. Marques, S. Fallon, and B. Furht, "Content-Based Multimedia Retrieval on the Internet," a chapter in the "Handbook of Internet Computing", CRC Press, Boca Raton, FL, 2000.
14. B. Furht, "Internet-Based Unified Messaging Systems," a chapter in the "Handbook of Internet Computing", CRC Press, Boca Raton, FL, 2000.
15. X. Li and B. Furht, "Design and Implementation of Digital Libraries," a chapter in the "Handbook of Internet Computing", CRC Press, Boca Raton, FL, 2000.
16. S. Brey and B. Furht, "Videoconferencing Systems and Applications," a chapter in the "Handbook of Internet Computing", CRC Press, Boca Raton, FL, 2000.
17. B. Furht, R. Westwater, and J. Ice, "Multimedia Broadcasting on the Internet", a chapter in the "Handbook of Internet Computing", CRC Press, Boca Raton, FL, 2000.
18. B. Furht, R. Westwater, and J. Ice, "A New Approach to Radio and Television Broadcasting over the Internet", a chapter in the book on "Interactive Television", by J. Jensen and C. Toscan (Eds.), Aalborg University Press, Denmark, 1999.
19. B. Furht, C. Phoenix, J. Yin, and Z. Aganovic, "Internet-Based Architectures for Application Service Providers," Chapter in the "Handbook of Internet Computing", Ed. B. Furht, CRC Press, Boca Raton, FL, 2000.
20. B. Furht, "Parallel Computing: Glory and Collapse," a chapter in the book "Computing Calamities" by R.L. Glass, Prentice-Hall, 1999.
21. B. Furht, "Multimedia Applications on the Internet", a chapter in the book "The Internet and Telecommunications: Architectures, Technologies, and Business Development", International Engineering Consortium, Chicago, IL, October 1998.
22. B. Furht, "Image Presentation and Compression", a chapter in the "Handbook of Multimedia Computing", CRC Press, Boca Raton, FL, 1999.
23. B. Furht and R. Westwater, "Video Presentation and Compression", a chapter in the "Handbook of Multimedia Computing", CRC Press, Boca Raton, FL, 1999.
24. J. Celli and B. Furht "Multimedia Support in Java", a chapter in the "Handbook of Multimedia Computing", CRC Press, Boca Raton, FL, 1999.
25. M. Kessler and B. Furht, "Hypermedia Techniques for Distributed Systems", a chapter in the "Handbook of Multimedia Computing", CRC Press, Boca Raton, FL, 1999.
26. B. Furht, "Processor Architectures for Multimedia", a chapter in the "Handbook of Multimedia Computing", CRC Press, Boca Raton, FL, 1999.

### Dr. Borko Furht's Publications

27. R. Westwater, J. Ice, and b. Furht, "Multimedia Broadcasting Over the Internet", a chapter in the Handbook of Internet and Multimedia Systems and Applications, CRC Press, Boca Raton, FL, 1999.
28. B. Furht, "Fifty Years of Computing", International Journal of Computers and Applications, Vol. 19, No. 1, 1997, pp. 1-3.
29. B. Furht, "Multimedia Compression Techniques and Standards", a chapter in the book "Real-Time Imaging: Theory, Techniques, and Applications", edited by P.A. Laplante and A.D. Stoyenko, IEEE Press, Piscataway, NJ, 1996, pp. 117-160.
30. B. Furht, D. Kalra, and A. Rodriguez, "Interactive Television Systems", a chapter in the book "Multimedia Tools and Applications", edited by B. Furht, Kluwer Academic Publishers, 1996.
31. H. Kalva and B. Furht, "Multimedia Networks", a chapter in the book "Multimedia Systems and Techniques", edited by B. Furht, Kluwer Academic Publishers, 1996.
32. B. Furht, "Where are Information Superhighways Headed?", Editorial, Journal of Multimedia Systems and Applications, Vol. 2, No. 1, January 1996, pp. 1-5.
33. B. Furht, "Compression Techniques and Standards", a chapter in the book "Multimedia Systems and Techniques", edited by B. Furht, Kluwer Academic Publishers, 1996.
34. B. Furht, "Multimedia Information Systems - A Survey", chapter in "Encyclopedia of Telecommunications", edited by F.E. Froehlich and A. Kent, Marcle Dekker, New York, 1996, pp. 117-146.
35. B. Furht, "Are Microprocessor Designers Finally Poised for Multimedia?", Editorial, Journal of Multimedia Systems and Applications, Vol. 1, No. 3, September 1995, pp. 215-216.
36. B. Furht, D. Kalra, F. Kitson, A.A. Rodriguez, and W.E. Wall, "Design Issues for Interactive Television Systems", in "Multimedia Networking Handbook", by J. Cavanagh, Auerbach Publishers, New York, 1995.
37. L. Ehley, M. Ilyas, and B. Furht, "A Survey of Multimedia Synchronization Techniques", in the book "A Guided Tour of Multimedia Systems and Applications", by B. Furht and M. Milenkovic, IEEE Computer Society Press, 1995, pp. 230-256.
38. B. Furht, "Where is Multimedia Headed?", Editorial, Journal of Multimedia Systems and Applications, Vol. 1, No. 1, March 1995, pp. 5-8.
39. B. Furht and H. Kalva, "Network Architectures for Interactive Television", abstract, Proc. of the Third INFORMS Telecommunications Conference, Boca Raton, Florida, March 1995, pp. 257.
40. B. Furht and W. Halang, "The Future of Real-Time and Embedded Computing Systems", in the book "Computer-Aided Control Systems Design", edited by M. Brdys and K. Malinowski, Singapore: World Scientific Publishers, 1994.
41. B. Furht, "Real-Time Systems Theory and Practice: Can We Bridge the Gap?", Proceedings of the NATO Advanced Study Institute on Real-Time Computing, Sent Martin, October 1992. (abstract)
42. B. Furht, "Next Generation of Real-Time Operating Systems", Proceedings of the NATO Advanced Study Institute on Real-Time Computing, Sent Martin, October 1992. (abstract)

# **Fundamentals of Multimedia Encryption Techniques**

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## **1. INTRODUCTION**

The recent advances in technology, especially in computer industry and communications, allowed potentially enormous market for distributing digital multimedia content through the Internet. However, the proliferation of digital documents, multimedia processing tools, and the worldwide availability of Internet access has created an ideal medium for copyright fraud and uncontrollable distribution of multimedia content [1]. A major challenge now is how to protect the intellectual property of multimedia content in multimedia networks.

To deal with the technical challenges, the two major multimedia security technologies are being developed:

- (1) Multimedia encryption technology to provide end-to-end security when distributing digital content over a variety of distributions systems, and

- (2) Multimedia watermarking technology as a tool to achieve copyright protection, ownership trace, and authentication.

In this chapter, we present the current research efforts in multimedia encryption, while the Chapter 7 gives an overview of multimedia watermarking techniques.

## 2. OVERVIEW OF MODERN CRYPTOGRAPHY

The three most important objectives of cryptography with respect to the multimedia information security include (1) confidentiality, (2) data integrity, and (3) authentication [3].

*Confidentiality* refers to the protection of information from unauthorized access. An undesired communicating party, called adversary, must not be able to access the communication material.

*Data integrity* ensures that information has not been manipulated in an unauthorized way. Finally,

*Authentication* methods are studied in two groups: *Entity* authentication and *message* authentication. Message authentication provides assurance of the identity of the sender of a message. This type of authentication also includes an evidence of data integrity because if the is modified during transmission, the sender cannot be the originator of the message. Entity authentication assures the receiver of a message of both the identity of the sender and his active participation.

Modern cryptographic techniques provide solutions for these three objectives. In general, there are two types of cryptosystems: (1) symmetric (private) key cryptosystems and (2) asymmetric (public) key cryptosystems.

## **2.1 SYMMETRIC KEY CRYPTOSYSTEMS**

All classical cryptosystems (that is cryptosystems that were developed before 1970s) are examples of symmetric key cryptosystems. In addition, most modern cryptosystems are symmetric as well. Some of the most popular examples of modern symmetric key cryptosystems include AES (Advanced Encryption Standard), DES (Data Encryption Standard), IDEA, FEAL, RC5, and many others. The AES algorithm will be further discussed in Section 2.4.

All symmetric key cryptosystems have a common property: they rely on a shared secret between communicating parties. This secret is used both as an encryption key and as a decryption key (thus the keyword "symmetric" in the name). This type of cryptography ensures only confidentiality and fails to provide the other objectives of cryptography. Even more importantly, the disadvantage of symmetric key cryptography is that it cannot handle large communication networks. If a node in a communication network of  $n$  nodes needs to communicate confidentially with all other nodes in the network, it needs  $n - 1$  shared secrets. For large value of  $n$  this is highly impractical and inconvenient. On the other hand, an advantage over public key cryptosystems is that symmetric cryptosystems require much smaller key sizes for the same level of security. Hence, the computations are much faster and the memory requirements are smaller.

## **2.2 PUBLIC KEY CRYPTOSYSTEMS**

In public key cryptosystems there are two different keys: a public key, which is publicly known, and the secret key, which is kept secret by the owner. The system is called "asymmetric" since the different keys are used for encryption and decryption— the public key and the private key. If data is encrypted with a public key, it can only be decrypted using the corresponding private key,



and vice versa. Today, all public key cryptosystems rely on some computationally intractable problems. For example, the cryptosystem RSA relies on the difficulty of factoring large integers, while El-Gamal cryptosystem relies on the discrete logarithm problem (DLP), which is the problem of finding a logarithm of a group element with generator base in a finite Abelian group.

Public key cryptosystems do not need to have a shared secret between communicating parties. This solves the problem of large confidential communication network introduced earlier. In addition, public key cryptography opened door for ways of implementing technologies to ensure all goals of cryptography. By means of combining public key cryptography, public key certification, and secure hash functions, there are protocols that enable digital signatures, authentication, and data integrity.

Due to the increase in processor speed and even more due to smart modern cryptanalysis, the key size for public key cryptography grew very large. This created a disadvantage in comparison to symmetric key cryptosystems: public key cryptography is significantly slower, and requires large memory capacity and large computational power. As an example, a 128-bit key used with DES cryptosystem has approximately the same level of security as the 1024-bit key used with RSA public key cryptosystem [5].

To solve these problems, researchers introduced different approaches. In order to decrease the key size so that public key cryptography can be used in smaller computational environments (such as smart cards or handheld wireless devices), Neil Koblitz introduced the idea of using a more exotic group in the public key underlying algebraic structure: the elliptic curve group. Elliptic curve cryptography (much of whose implementation is credited to CertiCom) enables smaller key sizes of public key cryptosystems that rely on DLP. The elliptic curve group algebra is much more complex so the related cryptanalysis is much harder, resulting in smaller key

requirements. Another solution came from public key cryptosystems that initially use more complex computational problem, such as the lattice reduction problem. The relatively new cryptosystem NTRU based on the algebra of a ring of truncated polynomials, relies on the lattice reduction problem and it is the only public key cryptosystem that has the speed, memory, and computational complexity comparable to the symmetric key cryptosystems. However, the security aspects of NTRU are yet to be investigated [19, 20]. The most common implementation solution is to combine symmetric key cryptosystems with public key cryptography. Namely, to overcome the problems related to applying the symmetric key encryption only, the plaintext is encrypted using a fast symmetric key scheme, and only the secret key used for the symmetric encryption is encrypted with the slow public key scheme such as RSA. This way all goals of cryptography can be achieved with much better performance.

## 2.3 CRYPTANALYSIS

Cryptanalysis is an art of deciphering an encrypted message in whole or in part, when the decryption key is not known. Depending on the amount of known information and the amount of control over the system by the adversary (cryptanalyst), there are several basic types of cryptanalytic attacks:

*Ciphertext-only attack:* The adversary only has access to one or more encrypted messages. The most important goal of a proposed cryptosystem is to withstand this type of attack.

*Brute force attack:* This is a type of ciphertext-only attack. It is based on exhaustive key search, and for well-designed cryptosystems should be computationally infeasible. By today's standards, 128-bit keys are considered secure against the brute force attack.

*Known-plaintext attack:* In this type of attack an adversary has some knowledge about the plaintext corresponding to the given ciphertext. This may help determine the key or a part of the key.

*Chosen-plaintext attack:* Essentially, an adversary can feed the chosen plaintext into the black box that contains the encryption algorithm and the encryption key. The black box spits out the corresponding ciphertext, and the adversary may use the accumulated knowledge about the plaintext-ciphertext pairs to obtain the secret key or at least a part of it.

*Chosen-ciphertext attack:* Here, an adversary can feed the chosen ciphertext into the black box that contains the decryption algorithm and the decryption key. The black box produces the corresponding plaintext, and the adversary tries to obtain the secret key or a part of the key by analyzing the accumulated ciphertext-plaintext pairs.

## 2.4 ADVANCED ENCRYPTION STANDARD (AES)

The AES algorithm is essentially Rijndael [38] symmetric key cryptosystem that processes 128-bit data blocks using cipher keys with lengths of either 128, 192, or 256 bits. Rijndael is more scalable and can handle different key sizes and data block sizes, however they are not included in the standard. Table 1 shows the basic AES parameters.

|         | Key Length<br>( $N_k$ words) | Blocksize<br>( $N_b$ words) | Number of<br>Rounds ( $N_r$ ) |
|---------|------------------------------|-----------------------------|-------------------------------|
| AES-128 | 4                            | 4                           | 10                            |
| AES-192 | 6                            | 4                           | 12                            |
| AES-256 | 8                            | 4                           | 14                            |

**Table 1.** The basic AES parameters.

The AES algorithm's internal operations are performed on a two-dimensional array of bytes called the *State*. The State consists of 4 rows of bytes, each containing  $Nb$  bytes, where  $Nb$  is the blocksize divided by 32 (since the size of a word is 32 bits), which is in the case of AES equal to 4. At the beginning of the encryption or decryption procedure, the input array *in*, is copied to the State array *s* according to the following rule:  $s[r, c] = in[r + 4c]$ , where  $0 = r < 4$  and  $0 = c < Nb$ . Similarly, at the end of each procedure, the State is copied to the output array *out* as follows:  $out[r + 4c] = s[r, c]$ , where  $0 = r < 4$  and  $0 = c < Nb$ . Clearly, in this notation *r* stands for row and *c* for column.

#### 2.4.1 AES Encryption

At the beginning of the AES encryption procedure, the input is copied to the State array using the conventions described above. After an initial Round Key addition (see next section), the State array is transformed by implementing a round function 10, 12, or 14 times (depending on the key length), with the final round differing slightly from the first  $Nr - 1$  rounds. The final State is then copied to the output as described above. Figure 1 shows the pseudo code for the AES encryption.

```

AesEncrypt(byte in[4*Nb], byte out[4*Nb], word w[Nb*(Nr+1)])
begin
    byte state[4,Nb]

    state = in

    AddRoundKey(state, w[0, Nb-1])

    for round = 1 step 1 to Nr-1
        SubBytes(state)
        ShiftRows(state)
        MixColumns(state)
        AddRoundKey(state, w[round*Nb, (round+1)*Nb-1])
    end for

    SubBytes(state)
    ShiftRows(state)
    AddRoundKey(state, w[Nr*Nb, (Nr+1)*Nb-1])

    out = state
end

```

**Figure 1.** Pseudo code for the AES encryption algorithm.

The `SubBytes()` transformation is essentially an S-box type of transform which is a non-linear byte substitution that operates independently on each byte of the State. The simplest representation of this S-box function is by the lookup table. The lookup table associated with `SubBytes()` is here shown in Table 2.

|   |   | y  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|   |   | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | a  | b  | c  | d  | e  | f  |
| x | 0 | 63 | 7c | 77 | 7b | f2 | 6b | 6f | c5 | 30 | 01 | 67 | 2b | fe | d7 | ab | 76 |
|   | 1 | ca | 82 | c9 | 7d | fa | 59 | 47 | f0 | ad | d4 | a2 | af | 9c | a4 | 72 | c0 |
|   | 2 | b7 | fd | 93 | 26 | 36 | 3f | f7 | cc | 34 | a5 | e5 | f1 | 71 | d8 | 31 | 15 |
|   | 3 | 04 | c7 | 23 | c3 | 18 | 96 | 05 | 9a | 07 | 12 | 80 | e2 | eb | 27 | b2 | 75 |
|   | 4 | 09 | 83 | 2c | 1a | 1b | 6e | 5a | a0 | 52 | 3b | d6 | b3 | 29 | e3 | 2f | 84 |
|   | 5 | 53 | d1 | 00 | ed | 20 | fc | b1 | 5b | 6a | cb | be | 39 | 4a | 4c | 58 | cf |
|   | 6 | d0 | ef | aa | fb | 43 | 4d | 33 | 85 | 45 | f9 | 02 | 7f | 50 | 3c | 9f | a8 |
|   | 7 | 51 | a3 | 40 | 8f | 92 | 9d | 38 | f5 | bc | b6 | da | 21 | 10 | ff | f3 | d2 |
|   | 8 | cd | 0c | 13 | ec | 5f | 97 | 44 | 17 | c4 | a7 | 7e | 3d | 64 | 5d | 19 | 73 |
|   | 9 | 60 | 81 | 4f | dc | 22 | 2a | 90 | 88 | 46 | ee | b8 | 14 | de | 5e | 0b | db |
|   | a | e0 | 32 | 3a | 0a | 49 | 06 | 24 | 5c | c2 | d3 | ac | 62 | 91 | 95 | e4 | 79 |
|   | b | e7 | c8 | 37 | 6d | 8d | d5 | 4e | a9 | 6c | 56 | f4 | ea | 65 | 7a | ae | 08 |
|   | c | ba | 78 | 25 | 2e | 1c | a6 | b4 | c6 | e8 | dd | 74 | 1f | 4b | bd | 8b | 8a |
|   | d | 70 | 3e | b5 | 66 | 48 | 03 | f6 | 0e | 61 | 35 | 57 | b9 | 86 | c1 | 1d | 9e |
|   | e | e1 | f8 | 98 | 11 | 69 | d9 | 8e | 94 | 9b | 1e | 87 | e9 | ce | 55 | 28 | df |
|   | f | 8c | a1 | 89 | 0d | bf | e6 | 42 | 68 | 41 | 99 | 2d | 0f | b0 | 54 | bb | 16 |

**Table 2.** AES Encryption S-box: substitution values for the byte  $xy$  (in hexadecimal representation).

In the `ShiftRows()` transformation, the bytes in the last three rows of the State are cyclically shifted over different numbers of bytes, while the first row is not shifted. The `ShiftRows()` transformation is defined as follows:  $s'[r, c] = s[r, (c + \text{shift}(r, Nb)) \bmod Nb]$  for  $0 = r < 4$  and  $0 = c < Nb$ , where the shift value  $\text{shift}(r, Nb)$  is defined in the following way:  $\text{shift}(1, 4) = 1$ ,  $\text{shift}(2, 4) = 2$ , and  $\text{shift}(3, 4) = 3$ .

The `MixColumns()` transformation operates on the State column-by-column. The columns are considered as polynomials over the Galois Field  $\text{GF}(2^8)$  and multiplied modulo  $x^4 + 1$  with a fixed polynomial  $a(x) = \{03\}x^3 + \{01\}x^2 + \{01\}x + \{02\}$ . Here, the notation  $\{h_1h_2\}$  denotes a byte in

the hexadecimal format. This can be accomplished by applying the following four equations to the State columns:

1.  $s'[0, c] = (\{02\} \bullet s[0, c]) \otimes (\{03\} \bullet s[1, c]) \otimes s[2, c] \otimes s[3, c]$
2.  $s'[1, c] = s[0, c] \otimes (\{02\} \bullet s[1, c]) \otimes (\{03\} \bullet s[2, c]) \otimes s[3, c]$
3.  $s'[2, c] = s[0, c] \otimes s[1, c] \otimes (\{02\} \bullet s[2, c]) \otimes (\{03\} \bullet s[3, c])$
4.  $s'[3, c] = (\{03\} \bullet s[0, c]) \otimes s[1, c] \otimes s[2, c] \otimes (\{02\} \bullet s[3, c])$

Here, the  $\bullet$  operation denotes multiplication in  $GF(2^8)$  modulo the polynomial  $x^4 + 1$ , while the  $\otimes$  denotes the usual bitwise XOR operation.

Finally, in the `AddRoundKey()` transformation, a Round Key is added to the State by a simple bitwise XOR operation. Each Round Key consists of  $Nb$  words from the key schedule (to be described in the next section), which are each added into the columns of the State.

```

KeyExpansion(byte key[4*Nk], word w[Nb*(Nr+1)], Nk)
begin
    word temp
    i = 0
    while (i < Nk)
        w[i] = word(key[4*i], key[4*i+1], key[4*i+2], key[4*i+3])
        i = i+1
    end while
    i = Nk
    while (i < Nb * (Nr+1))
        temp = w[i-1]
        if (i mod Nk = 0)
            temp = SubWord(RotWord(temp)) xor Rcon[i/Nk]
        else if (Nk > 6 and i mod Nk = 4)
            temp = SubWord(temp)
        end if
        w[i] = w[i-Nk] xor temp
        i = i + 1
    end while
end

```

**Figure 2.** Pseudo code of the key schedule stage of the AES algorithm.

### 2.4.2 AES Key Schedule

In the AES algorithm, the initial input symmetric key is expanded to create a key schedule for each round. This procedure, given in Figure 2, generates a total of  $Nb(Nr + 1)$  words that are used in the `AddRoundKey()` procedure. In this algorithm, `SubWord()` is a function that takes a four-byte input word and applies the S-box to each of the four bytes to produce an output word. The function `RotWord()` takes a word  $[a_0, a_1, a_2, a_3]$  as input, performs a cyclic permutation, and returns the word  $[a_1, a_2, a_3, a_0]$ . The round constant word array, `Rcon[i]`, contains the values given by  $[x^{i-1}, \{00\}, \{00\}, \{00\}]$ , with  $x^{i-1}$  being powers of  $x$  ( $x$  is denoted as  $\{02\}$ ) in the field  $GF(2^8)$ .

```
AesDecrypt(byte in[4*Nb], byte out[4*Nb], word w[Nb*(Nr+1)])
begin
    byte state[4,Nb]
    state = in
    AddRoundKey(state, w[Nr*Nb, (Nr+1)*Nb-1])
    for round = Nr-1 step -1 downto 1
        InvShiftRows(state)
        InvSubBytes(state)
        AddRoundKey(state, w[round*Nb, (round+1)*Nb-1])
        InvMixColumns(state)
    end for
    InvShiftRows(state)
    InvSubBytes(state)
    AddRoundKey(state, w[0, Nb-1])
    out = state
end
```

**Figure 3.** Pseudo code of AES decryption algorithm.

### 2.4.3 AES Decryption

AES decryption, the inverse of AES encryption, also consists of four stages in each round, which are simply the inverses of the transformations described above. Each AES decryption round

performs the following four transformations: `InvShiftRows()`, `InvSubBytes()`, `InvMixColumns()`, and `AddRoundKey()`. The pseudo code for the AES decryption process is given in Figure 3.

The `InvShiftRows()` is the inverse of the `ShiftRows()` transformation, which is defined as follows:  $s[r, c] = s'[r, (c + \text{shift}(r, Nb)) \bmod Nb]$  for  $0 = r < 4$  and  $0 = c < Nb$ . Similarly, `InvSubBytes()` is the inverse of the byte substitution transformation, in which the inverse S-box is applied to each byte of the State. The inverse S-box used in the `InvSubBytes()` transformation is presented in Table 3.

|   |   | Y  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
|   |   | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | a  | b  | c  | d  | e  | f  |
| x | 0 | 52 | 09 | 6a | d5 | 30 | 36 | a5 | 38 | bf | 40 | a3 | 9e | 81 | f3 | d7 | fb |
|   | 1 | 7c | e3 | 39 | 82 | 9b | 2f | ff | 87 | 34 | 8e | 43 | 44 | c4 | de | e9 | cb |
|   | 2 | 54 | 7b | 94 | 32 | a6 | c2 | 23 | 3d | ee | 4c | 95 | 0b | 42 | fa | c3 | 4e |
|   | 3 | 08 | 2e | a1 | 66 | 28 | d9 | 24 | b2 | 76 | 5b | a2 | 49 | 6d | 8b | d1 | 25 |
|   | 4 | 72 | f8 | f6 | 64 | 86 | 68 | 98 | 16 | d4 | a4 | 5c | cc | 5d | 65 | b6 | 92 |
|   | 5 | 6c | 70 | 48 | 50 | fd | ed | b9 | da | 5e | 15 | 46 | 57 | a7 | 8d | 9d | 84 |
|   | 6 | 90 | d8 | ab | 00 | 8c | bc | d3 | 0a | f7 | e4 | 58 | 05 | b8 | b3 | 45 | 06 |
|   | 7 | d0 | 2c | 1e | 8f | ca | 3f | 0f | 02 | c1 | af | bd | 03 | 01 | 13 | 8a | 6b |
|   | 8 | 3a | 91 | 11 | 41 | 4f | 67 | dc | ea | 97 | f2 | cf | ce | f0 | b4 | e6 | 73 |
|   | 9 | 96 | ac | 74 | 22 | e7 | ad | 35 | 85 | e2 | f9 | 37 | e8 | 1c | 75 | df | 6e |
|   | a | 47 | f1 | 1a | 71 | 1d | 29 | c5 | 89 | 6f | b7 | 62 | 0e | aa | 18 | be | 1b |
|   | b | fc | 56 | 3e | 4b | c6 | d2 | 79 | 20 | 9a | db | c0 | fe | 78 | cd | 5a | f4 |
|   | c | 1f | dd | a8 | 33 | 88 | 07 | c7 | 31 | b1 | 12 | 10 | 59 | 27 | 80 | ec | 5f |
|   | d | 60 | 51 | 7f | a9 | 19 | b5 | 4a | 0d | 2d | e5 | 7a | 9f | 93 | c9 | 9c | ef |
|   | e | a0 | e0 | 3b | 4d | ae | 2a | f5 | b0 | c8 | eb | bb | 3c | 83 | 53 | 99 | 61 |
|   | f | 17 | 2b | 04 | 7e | ba | 77 | d6 | 26 | e1 | 69 | 14 | 63 | 55 | 21 | 0c | 7d |

**Table 3.** AES Decryption S-box: substitution values for the byte xy (in hexadecimal representation).

The `InvMixColumns()` is the inverse of the `MixColumns()` transformation. The transformation `InvMixColumns()` operates on the State column-by-column, treating each column as a polynomial over the field  $GF(2^8)$  modulo  $x^4 + 1$  with a fixed polynomial  $a^{-1}(x)$ , given by  $a^{-1}(x) = \{0b\}x^3 + \{0d\}x^2 + \{09\}x + \{0e\}$ . This can be accomplished by applying the following four equations to the State columns:



1.  $s'[0, c] = (\{0e\} \bullet s[0, c]) \otimes (\{0b\} \bullet s[1, c]) \otimes (\{0d\} \bullet s[2, c]) \otimes (\{09\} \bullet s[3, c])$
2.  $s'[1, c] = (\{09\} \bullet s[0, c]) \otimes (\{0e\} \bullet s[1, c]) \otimes (\{0b\} \bullet s[2, c]) \otimes (\{0d\} \bullet s[3, c])$
3.  $s'[2, c] = (\{0d\} \bullet s[0, c]) \otimes (\{09\} \bullet s[1, c]) \otimes (\{0e\} \bullet s[2, c]) \otimes (\{0b\} \bullet s[3, c])$
4.  $s'[3, c] = (\{0b\} \bullet s[0, c]) \otimes (\{0d\} \bullet s[1, c]) \otimes (\{09\} \bullet s[2, c]) \otimes (\{0e\} \bullet s[3, c])$

Finally, the  $\text{AddRoundKey}()$  is identical to the one from the AES encryption procedure, since this transformation is its own inverse.

The security level of AES is to this day substantial since there are no known effective attacks discovered thus far. For more information about AES please refer to [38].

### 3. INTRODUCTION TO MULTIMEDI SECURITY

Multimedia security in general is provided by a method or a set of methods used to protect the multimedia content. These methods are heavily based on cryptography and they enable either communication security, or security against piracy (Digital Rights Management and watermarking), or both. Communication security of digital images and textual digital media can be accomplished by means of standard symmetric key cryptography. Such media can be treated as binary sequence and the whole data can be encrypted using a cryptosystem such as AES or DES [6]. In general, when the multimedia data is static (not a real-time streaming) we can treat it as a regular binary data and use the conventional encryption techniques. Encrypting the entire multimedia stream using standard encryption methods is often referred to as the *naive approach*.

However, due to variety of constraints (such as the near real-time speed, etc.), communication security for streaming audio and video media is harder to accomplish. Communication encryption

of video and audio multimedia content is not simply the application of established encryption algorithms, such as DES or AES, to its binary sequence. It involves careful analysis to determine and identify the optimal encryption method when dealing with audio and video data. Current research is focused on modifying and optimizing the existing cryptosystems for real-time audio/video. It is also oriented towards exploiting the format specific properties of many standard video and audio formats in order to achieve the desired speed and enable real-time streaming. This is referred to as the *selective encryption*.

For textual data, most applications of still images, and some low-quality audio and video streaming multimedia, we can still apply real-time packet encryption by means of SRTP (Secure Real-time Transport Protocol) [31], which is based on AES and encrypts the entire multimedia bit stream. This is essentially an application of the naive approach.

Deciding upon what level of security is needed is harder than it looks. To identify an optimal security level, we have to carefully compare the cost of the multimedia information to be protected and the cost of the protection itself. If the multimedia to be protected is not that valuable in the first place, it is sufficient to choose relatively light level of encryption. On the other hand, if the multimedia content is highly valuable or represents government or military secrets, the cryptographic security level must be the highest possible.

For many real-world applications such as pay-per-view, the content data rate is typically very high, but the monetary value of the content may not be high at all. Thus, very expensive attacks are not attractive to adversaries, and light encryption (often called *degradation*) may be sufficient for distributing MPEG video. For these applications, DRM is of much more interest. In contrast, applications such as videoconferencing or videophone (or even Internet phone) may require much higher level of confidentiality. If the videoconference is discussing important industrial,

governmental or military secrets, then the cryptographic strength must be substantial. Maintaining such high level of security and still keeping the real-time and limited-bandwidth constraints is not easy to accomplish.

Comprehensive survey studies of the multimedia encryption techniques are given in [2, 4, 34]. In [4], Liu and Eskicioglu present a comprehensive classification that summarizes most of the presented algorithms. An updated version of that classification is shown in Table 4.

**Table 4.** Classification of Selective Encryption Schemes, adapted from [4].

| Type of data | Domain           | Proposal                                     | Encryption Algorithm  | What is encrypted?  |
|--------------|------------------|--|---|---|
| Image        | Frequency domain | Cheng & Li, 2000 [23]                        | No algorithm is specified.                                      | Pixel and set related significance information in the two highest pyramid levels of SPIHT   |
|              |                  | Droogenbroeck & Benedett, 2002 [28]          | DES, Triple DES and IDEA  | Bits that indicate the sign and magnitude of the non-zero DCT coefficients  |
|              |                  | Pommer & Uhl, 2003 [37]                      | AES   | Subband decomposition structure   |
|              | Spatial domain   | Cheng & Li, 2000 [23]                        | No algorithm is specified.                                      | Quadtree structure  |
|              |                  | Droogenbroeck & Benedett, 2002 [28]          | Xor   | Least significant bitplanes   |
|              |                  | Podesser, Schmidt & Uhl, 2002 [35]           | AES   | Most significant bitplanes  |
| Video        | Frequency domain | Meyer & Gadegast, 1995 [9]                   | DES, RSA  | Headers, parts of I-blocks, all I-blocks, I-frames of the MPEG stream   |
|              |                  | Spanos & Maples, 1995 [7,8]                  | DES   | I-frames, sequence headers and ISO end code of the MPEG stream  |
|              |                  | Tang, 1996 [10]                              | Permutation, DES  | DCT coefficients  |
|              |                  | Qiao & Nahrstedt, 1997 [12]                  | xor, permutation, IDEA  | Every other bit of the MPEG bit stream  |
|              |                  | Shi & Bhargava, 1998 [15]                    | xor   | Sign bit of DCT coefficients  |
|              |                  | Shi, Wang & Bhargava, 1999 [16]              | IDEA  | Sign bit of motion vectors  |
|              |                  | Alattar, A-Regib and Al-Semari, 1999 [22]    | DES   | Every $n^{\text{th}}$ I-macroblock, headers of all the predicted macroblocks, header of every $n^{\text{th}}$ predicted macroblock      |
|              |                  | Shin, Sim & Rhee, 1999 [32]                  | Permutation, RC4  | Sign bits of DC coefficients of I pictures. Random permutation of the DCT coefficients  |
|              |                  | Cheng & Li, 2000 [23]                        | No algorithm is specified.                                      | Pixel and set related significance information in the two highest pyramid levels of SPIHT in the residual error                         |
|              |                  | Wen, Severa, Zeng, Luttrell & Jin, 2002 [26] | DES, AES  | The information-carrying fields, either fixed length code (FLC) codewords, or variable length code (VLC) codewords                      |
|              |                  | Zeng & Lei, 2002 [27]                        | Permutation, xor  | Selective bit scrambling, block shuffling, block rotation of the transform coefficients (wavelet and JPEG) and JPEG motion vectors      |
|              |                  | Wu & Mao, 2002 [33]                          | Any modern cipher, random shuffling on bit-planes in MPEG-4 FGS | Bitstream after entropy coding, quantized values before run length coding (RLC) or RLC symbols, intra bit-plane shuffling in MPEG-4 FGS |
|              | Spatial domain   | Cheng & Li, 2000 [23]                        | No algorithm is specified.                                      | Quadtree structure of motion vectors and quadtree structure of residual errors  |

|        |                   |   |   |  |
|--------|-------------------|---|---|--|
|        | Entropy codec     | Wu & Kuo, 2000 [24]; Wu & Kuo, 2001 [25]    | Multiple Huffman tables, multiple state indices in the QM coder | Encryption of data by multiple Huffman coding tables and multiple state indices in the QM coder  |
| Speech | Compressed domain | Wu & Kuo, 2000 [24]                         | DES, AES  | Most significant bits of the LSP codebook indices, the lag of pitch predictor, the pitch gain vectors, the fixed codebook gains, and the VAD mode flag coefficients of the G.723.1 speech codec  |
|        |                   | Servetti & De Martin, 2002 [29]             | Not specified   | 1 <sup>st</sup> stage vector of LSP quantizer, 2 <sup>nd</sup> stage lower vector of LSP quantizer, pitch delay 1 <sup>st</sup> subframe, pitch delay 2 <sup>nd</sup> subframe, gain codebook (stage 1) 1 <sup>st</sup> subframe, gain codebook (stage 2) 1 <sup>st</sup> subframe, gain codebook (stage 1) 2 <sup>nd</sup> subframe, gain codebook (stage 2) 2 <sup>nd</sup> subframe |
| Audio  | Compressed domain | Servetti, Testa & De Martin, 2003 [30]      | Not specified   | File header (that contains the original <i>table_select</i> and <i>big_value</i> values) at the beginning of the audio track; a subset of region1 bits and a subset of region2 bits.   |
|        |                   | Thorwirth, Horvatic, Weis & Zhao, 2000 [36] | Not specified   | Audio quality layers associated with the compressed audio data   |

## 4. VIDEO ENCRYPTION TECHNIQUES

In this section we discuss different research directions, which were taken in the area of video communication encryption. As discussed earlier, a naive approach can be used to encrypt multimedia content. The whole multimedia stream is encrypted using a symmetric key cryptosystem. However, even the fastest modern symmetric schemes, such as DES or AES, are computationally very expensive for many real-time video and audio data.

### 4.1 VIDEO SCRAMBLING

Scrambling is a popular method of applying fast, yet very insecure distortion of the video signal. In general, scrambling was the product of immediate industrial need by cable companies for a fast solution to make the free viewing of paid cable channels more difficult than doing nothing to the video signal.

Even though there is no distinct definition of scrambling, it refers to the simplest possible encryption attempts such as simple substitution or simple transposition ciphers whose security in

the modern world is the lowest possible. Early work on signal scrambling was based on using an analog device to permute the signal in the time domain or distort the signal in the frequency domain by applying filter banks or frequency converters [25]. However, these schemes seriously lack security, and they are extremely easy to crack using modern computers. As far as the attacker is concerned, those methods represent a temporary inconvenience in getting the original video or audio signal.

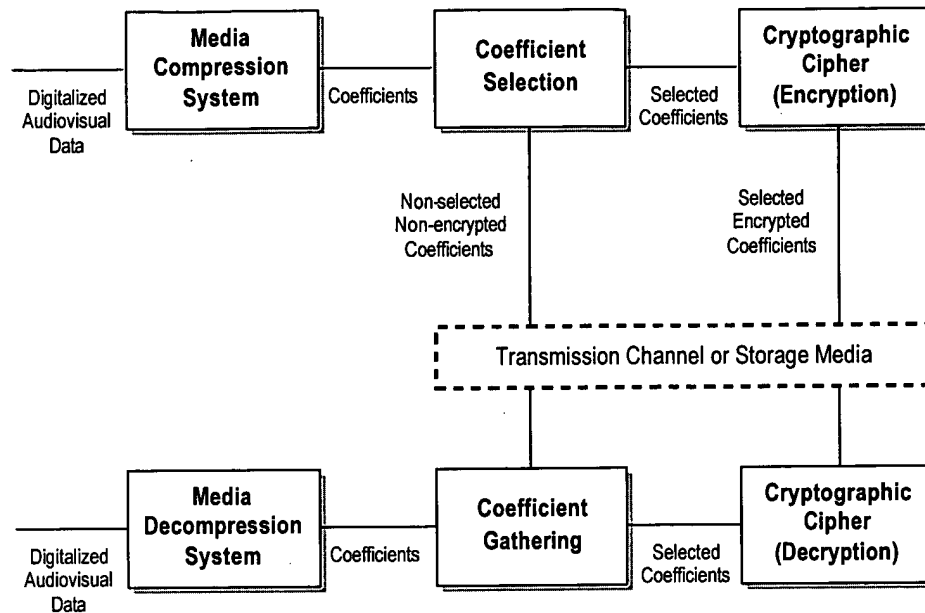
In many instances, this is still a solution that serves cable companies around the world quite effectively since most people lack the knowledge and engineering skills to crack the scrambled video signal, but the modified cable boxes that can unscramble all scrambled material are quite easy to manufacture. However, scrambling is out of the question for the applications that require more serious level of security.

## 4.2 SELECTIVE VIDEO ENCRYPTION

In order to meet real-time constraint for audio and video multimedia playback, *selective encryption* techniques have been proposed. The basic idea of selective encryption is to encrypt only a portion of the compressed bit-stream. A common approach in selective encryption is to integrate compression with encryption as shown in Figure 4.

For example, we can select only the most important coefficients from either final or intermediate steps of a compression process and encrypt those coefficients. Less important coefficients are left unencrypted. Still, some schemes prefer to lightly encrypt even these less important coefficients. By “light” encryption we mean applying a simple encryption scheme whose speed is high and whose security level is low (there is always a trade-off between the speed and security). In this manner, we define *variable encryption* as an approach that applies different encryption schemes

with different security strengths. Selective encryption can be treated as a special case of variable encryption [34].



**Figure 4.** A common selective encryption scheme.

#### 4.2.1 SECMPPEG by Meyer and Gadegast, 1995

In 1995 Meyer and Gadegast introduced the selective encryption method called *Secure MPEG*, or shortly *SECMPPEG*, designed for the MPEG-1 video standard [9]. The SECMPPEG contains four different levels of security. At the first level, SECMPPEG encrypts the headers from the sequence layer to the slice layer, while the motion vectors and DCT blocks are unencrypted. At the second level, most relevant parts of the I-blocks are additionally encrypted (upper left corner of the block). At the third level, SECMPPEG encrypts all I-frames and all I-blocks. Finally, at the fourth level, SECMPPEG encrypts the whole MPEG-1 sequence (the naive approach). The authors chose Data Encryption Standard (DES) symmetric key cryptosystem, which was the natural choice, given that this cryptosystem had been around since 1976 and was the official symmetric

encryption algorithm standardized by NIST and adopted by the US Government. Since DES is a symmetric key cryptosystem, it could only be used to achieve confidentiality. Meyer and Gadegast targeted solving the problem of data integrity as well. For that reason, the Cyclic-Redundancy-Check (CRC) was incorporated as a low-level solution to the integrity. The real data integrity mechanisms that included public key cryptography and cryptographically good hash functions such as MD4, MD5, or SHA were left for further research.

The selective encryption in SECMPEG (levels 1, 2, and 3) has some weaknesses [11,13]. It is shown that even though single P- or B-frame on its own carries almost no information without the corresponding I-frame, a series of P- or B-frames can tell a lot if their base I-frames are correlated. The experiments by Agi and Gong showed that encrypting I-frames only might leave visible I-blocks in other frames [11]. The same authors then propose a few trade-off improvements: increasing the frequency of the I-frames and/or encrypting all P- and B-frames. These improvements decrease speed, and further disrupt the compression ratio. Since SECMPEG introduces changes to the MPEG-1 format, a special encoder and decoder is needed to handle SECMPEG streams.

Nevertheless, the SECMPEG paper [9] and implementation by Meyer and Gadegast was one of the first important research initiatives for selective encryption of multimedia streams. These authors were among the first to realize the benefits of encrypting only selected bits in a video bit-stream. Their experiments confirmed that the visual disruption was substantial when only encrypting the DC coefficients and the first 38 AC coefficients in the 8x8 JPEG block of the MPEG-1 I-frames.

#### 4.2.2 Aegis by Maples and Spanos, 1995

Another important research achievement on selective encryption of MPEG video stream appeared in 1995 by Maples and Spanos [7,8], and it introduced the secure MPEG video mechanism called *Aegis*. *Aegis* was initially designed for MPEG-1 and MPEG-2 video standards. *Aegis* method encrypts I-frames of all MPEG groups of frames in an MPEG video stream, while B- and P-frames are left unencrypted. In addition, *Aegis* also encrypts the MPEG video sequence header, that contains all of the decoding initialization parameters that include the picture width, height, frame rate, bit rate, buffer size, etc. Finally, this method also encrypts the ISO end code; i.e., the last 32 bits of the stream. As a result, the bit-stream's MPEG identity is further concealed. The *Aegis*' behind-the-scenes encryption engine chosen by Maples and Spanos was DES. In a way, *Aegis* is very similar to the level 3 of SECMPEG by Meyer and Gadegast, and the security weaknesses that are applicable to SECMPEG are carried over to *Aegis*.

As discussed earlier, Agi and Gong criticized encrypting only I-frames by *Aegis* and SECMPEG, in view of the fact that their experiments showed that it is possible to discern some aspects from the scene from the decoded P- and B-frames [11]. For example, they were able to conclude that the talking head was present at the scene. Alattar and Al-Regib presented the similar argument regarding the security of SECMPEG in [21]. It is important to notice that this type of security is not particularly good for applications where the security is one of the top priorities (such as the important military or business teleconferencing) but it might be sufficient as a quality degradation of the entertainment videos, such as the pay TV broadcast.

*Aegis* is also considered as one of the pioneering research accomplishments in the area of selective video encryption. The experimental results for the selective encryption published by



Maples and Spanos in [7,8] confirmed the enormous gain in speed over the naive approach, by applying the selective encryption.

#### 4.2.3 Zigzag Permutation Algorithm by Tang, 1996

Tang's *Zigzag permutation algorithm* [10] is based on embedding the encryption into the MPEG compression process. The JPEG images and the Iframes of MPEG video undergo a zigzag reordering of the 8x8 blocks. The zigzag pattern forms a sequence of 64 entries that are ready to enter entropy-encoding stage. The main idea of this approach is to use a random permutation list to map the individual 8x8 blocks to a 1x64 vector. The algorithm consists of three stages:

- *Stage 1:* A list of 64 permutations is generated.
- *Stage 2:* Splitting procedure on an 8x8 block is performed as follows: we denote DC coefficient by an 8 digit binary number with digits  $b_7b_6b_5b_4b_3b_2b_1b_0$ . This binary sequence is then split into two equal halves:  $b_7b_6b_5b_4$  and  $b_3b_2b_1b_0$ . Finally, we place number  $b_7b_6b_5b_4$  into DC coefficient and the number  $b_3b_2b_1b_0$  as the  $AC_{63}$  (the last AC coefficient), which is the least important value in the block. This will result in no visible degradation of the quality.
- *Stage 3:* The random permutation is applied to the split block.

However, the zigzag permutation algorithm is not particularly secure [13,14]. Qiao and Nahrstedt introduced two types of attacks on zigzag permutation: a known-plaintext attack, and a ciphertext-only attack. A known-plaintext attack is particularly applicable to the videos with known clips such as blank screens, the movie rating screens, MGM roaring lion, etc. If these known frames are used as a comparison, the adversary can easily generate the secret permutation list.

Since Tang himself realized large vulnerability to known-plaintext attack, he introduced an improvement of the zigzag permutation technique by using the binary coin flipping sequence method together with two different permutation lists. Two different permutation lists are generated and for each 8x8 block a coin is randomly flipped. The outcome event determines which list to apply; i.e., if the head is flipped we apply one list and if the tail is flipped we apply the other list. As shown in [13,14], this addition turns out to be useless. If we know some of the original frames in advance (known-plaintext) then by simple comparison both permutation lists can be found. Since of the certain statistical properties of the blocks (upper left corner gathering of the AC coefficients within a block), we can easily determine which list of permutations is used.

In addition, Qiao and Nahrstedt showed that the Tang's splitting method is just a subset of SECMPPEG with second level, and thus its security is not good. Finally, Qiao and Nahrstedt showed that the Tang's zigzag permutation algorithm is susceptible to the ciphertext-only attack. The attack relies on the statistical properties of the DCT coefficients where most non-zero terms are gathered in the top left corner of the Iblock. Statistical analysis shows the following observation [13]: the DC coefficient always has the highest frequency value, the frequencies of  $AC_1$  and  $AC_2$  coefficients are among top 6, and frequencies of  $AC_3$  and  $AC_4$  are among top 10. Applying these observations, one can reconstruct the original video a relatively the good accuracy using only five DCT coefficients. Therefore, zigzag permutation cipher seriously lacks the desired level of security.

#### 4.2.4 Video Encryption Algorithm by Qiao and Nahrstedt, 1997

The *Video Encryption Algorithm (VEA)* by Qiao and Nahrstedt [12] is constructed with the goal to exploit the statistical properties of the MPEG video standard. The algorithm consists of the following four steps:

- *Step 1:* Let the  $2n$  byte sequence, denoted by  $a_1a_2\dots a_{2n}$ , represent the chunk of an I-frame
- *Step 2:* Create two lists, one with odd indexed bytes  $a_1a_3\dots a_{2n-1}$ , and the other with even indexed bytes  $a_2a_4\dots a_{2n}$ .
- *Step 3:* Xor the two lists into an  $n$ -byte sequence denoted with  $c_1c_2\dots c_n$
- *Step 4:* Apply the chosen symmetric cryptosystem  $E$  (for example DES or AES) with the secret key  $KeyE$  on either odd list or even list, and thus create the ciphertext sequence  $c_1c_2\dots c_nE_{KeyE}(a_1a_3\dots a_{2n-1})$  or  $c_1c_2\dots c_nE_{KeyE}(a_2a_4\dots a_{2n})$  respectively.<sup>1</sup>

Clearly, the decryption mechanism at the other end of the communication channel consists of two easy steps: Apply the symmetric cryptosystem  $E$  with the appropriate key to the second half of the ciphertext to obtain the first half of the original sequence, and xor this result with the first half of the ciphertext to obtain the other half of the original sequence.

Even though the security of the system is based on the security of the chosen underlying cryptosystem, if an adversary obtains either even or odd list, the system is completely broken. Thus, the authors suggest an even more secure approach. Instead of dividing the list into the even and odd lists, the random  $2n$ -bit key, called  $KeyM$ , is generated and used to split the  $2n$ -byte chunk of MPEG stream into two lists. The method of partitioning the  $2n$ -byte MPEG sequence

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<sup>1</sup> The authors' choice was to encrypt the even sequence creating the ciphertext  $c_1c_2\dots c_nE_{KeyE}(a_2a_4\dots a_{2n})$

into two subsequences is as follows: if  $i^{\text{th}}$  bit in  $KeyM$  is 1 then the  $i^{\text{th}}$  byte of the MPEG sequence goes into the first subsequence, and similarly, if  $i^{\text{th}}$  bit in  $KeyM$  is 0 then the  $i^{\text{th}}$  byte of the MPEG sequence goes into the second subsequence. It is required that  $KeyM$  is a binary sequence with exactly  $n$  ones and  $n$  zeros, in order to ensure that the two lists are of the equal length. The suggested values for  $n$  are 64 or 128. By applying this approach, the attacker will have a very hard time ordering the resulting sequence of bytes in the case that the encrypted subsequence is somehow cracked, assuming that the binary sequence  $KeyM$  remained secret. This means that  $KeyM$  must be securely transmitted to the receiver before the decryption can take place.

Another consideration is that a possible pattern repetition in the  $2n$  stream chunk represents a significant security hole in the method proposed by Qiao and Nahrstedt. According to the statistical analysis of MPEG stream sequences, it was observed that the non-repeating patterns have a lifetime over only one 1/16 chunk [12]. Therefore, to obtain the non-repeating pattern with a length of 1/2 frame, which is consisted of 8 such chunks, it is sufficient to shuffle only these 8 chunks. However, each of these chunks must be shuffled by using different keys, which are here denoted by  $Key_1, Key_2, \dots, Key_8$ . The authors suggest using the permutations of degree 32 (even though the degree 24 was shown to be sufficient), so that each  $Key_i$  is stored as a random permutation of degree 32. Hence, the length of a  $Key_i$  is 20 bytes, resulting in the total length of 160 bytes for  $Key_1, Key_2, \dots, Key_8$ . Once the keys are generated,  $Key_1$  permutation is applied to the first 32 bytes of even list,  $Key_2$  permutation is applied to the next 32 bytes, and so on, repeating this process after the 8<sup>th</sup> key. This procedure will ensure the non-repetition in the MPEG stream, thus significantly decreasing the vulnerability of the system to the repetitive pattern attacks. Furthermore, the increase in the bit-stream size caused by including these extra keys is at a negligible level.

Finally, Qiao and Nahrstedt proposed the use of one more additional key, denoted by  $KeyF$ . The experiments have shown that the pattern of selecting the even list and the odd list should be changed for every frame in order to ensure the anticipated security level [12]. For this reason, a 64-bit key  $KeyF$  is randomly generated for every single frame in the MPEG sequence. However, this key is subject to the constraint that every 4 consecutive bits represent a unique number from 0 to 15; i.e., so that any  $KeyF$  represents a permutation of degree 16. To get the new keys for each frame, we permute  $KeyM$  and  $Key_i$ 's repeatedly using the permutation defined by  $KeyF$  assigned to that frame.

In order to securely transmit these additional keys ( $KeyM$ ,  $Key_i$ 's and  $KeyF$ 's), they must be encrypted using the encryption function  $E$  with  $KeyE$ . As a final point, the secret key  $KeyE$  has to be securely transmitted to the decoder's side (the receiver), possibly by using the public key cryptography, or by using the separate secure channel. Alternatively, the separate secure channel can be used for the transmission of keys  $KeyM$  and  $Key_i$ 's. The diagram of the proposed algorithm is shown in Figure 5.

The experiments that were originally performed in 1997 were mainly using DES and IDEA cryptosystems; however, the newer choice for the underlying cryptosystem  $E$  would probably be the recently standardized AES cryptosystem (Rijndael). The security of method proposed by Qiao and Nahrstedt is very close to the security of encryption scheme  $E$  that is internally used. The speed of this algorithm is roughly a half of the speed of naive algorithm, but that is arguably still the large amount of computation for high quality real-time video applications that have high bit rates [25].

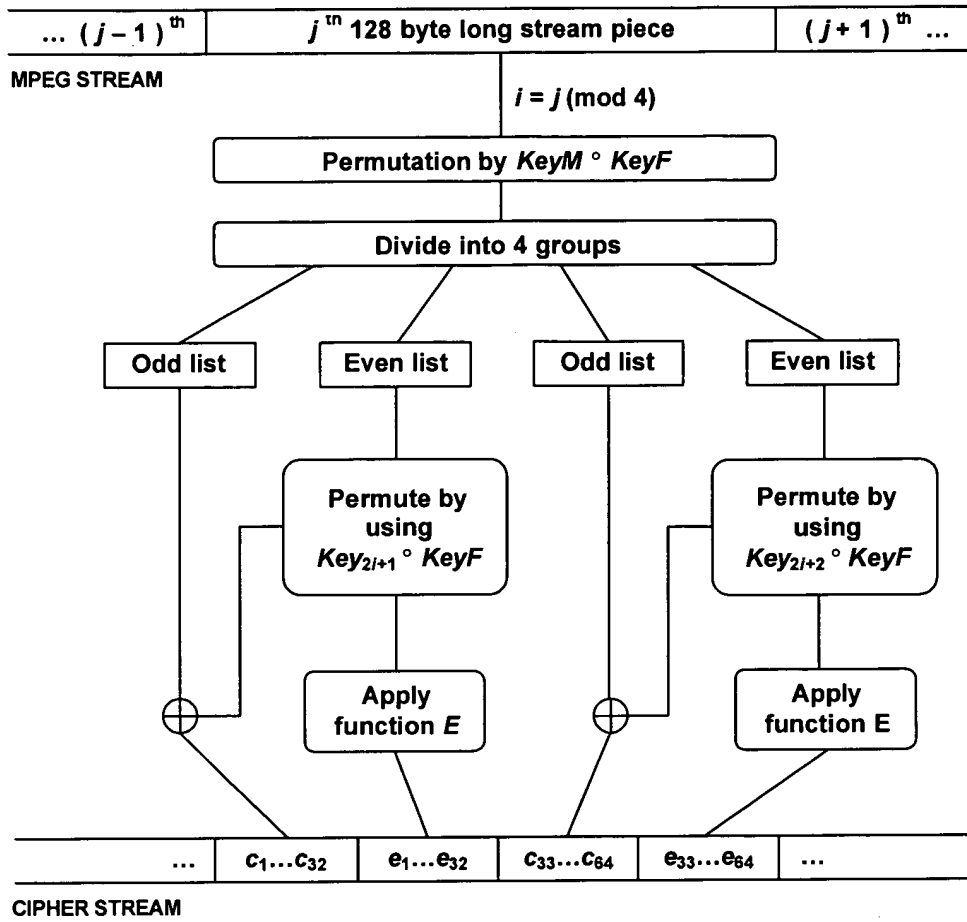
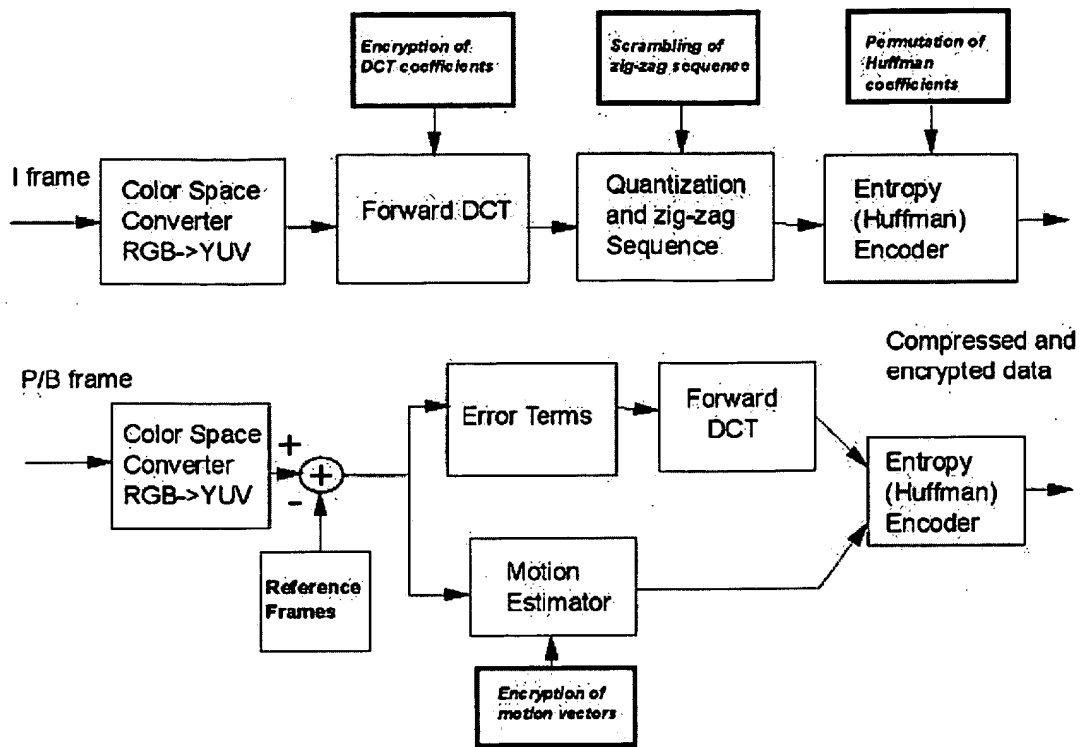


Figure 5. Selective Video Encryption Algorithm by Qiao and Nahrstedt [12].

#### 4.2.5 Video Encryption Algorithms by Shi, Wang and Bhargava, 1998 and 1999

In [17], Shi Wang and Bhargava classified their previous work into four different video encryption algorithms: *Algorithm I*, *Algorithm II (VEA)*, *Algorithm III (MVEA)*, and *Algorithm IV (RVEA)*. The original work was published by the same authors years earlier [15,16]. The basic ideas of these algorithms is to apply selective encryption on selective coefficients in the JPEG/MPEG schemes, as illustrated in Figure 6.



**Figure 6.** Selective encryption of selective coefficients in MPEG/JPEG coding schemes: DCT and its zig-zag sequence, coefficients in the Huffman table, and motion vectors.

### Algorithm I

The first algorithm, denoted simply by the Algorithm I, uses the permutation of Huffman codewords in the I-frames. This method incorporates encryption and compression in one step. The secret part of the algorithm is a permutation  $p$ , which is used to permute standard JPEG/MPEG Huffman codeword list. In order to save compression ratio, the permutation  $p$  must be such that it only permutes the codewords with the same number of bits. In addition, the distance between the original and the permuted codeword list must be greater than the encryption quality parameter  $\beta$ , which is chosen by the user.

The security of Algorithm I is not particularly good. In [18], it is shown that the Algorithm I is highly vulnerable to both known-plaintext attack, and ciphertext-only attack. If some of the video frames are known in advance (such as standard introductory jingles and similar), one can reconstruct the secret permutation  $p$  by comparing the original and encrypted frames. Vulnerability to this type of attack was also discussed in [17]. However, Algorithm I is also subject to ciphertext-only attack. The low-frequency error attack can be applied on ciphertext produced by Algorithm I [18]. Basically, since permutation  $p$  is of the special form; i.e., it only shuffles codewords with the same length, the most security comes from shuffling the 16-bit codewords in the AC coefficient entropy table. However, since there is a very limited number of codewords with length of less than 16 bits, it is very easy to reconstruct all of the DC coefficients and most frequent AC coefficients (since these will be encoded with less than 16-bit codewords). In other words, the only hard part would be to figure out how does the permutation  $p$  shuffle the 16-bit codewords. But these are appearing extremely rare, and the reconstructed video may be of almost the same quality as the original. Furthermore, the rare pixels that do contain 16-bit codewords can easily be interpolated to get rid of the noise effect and to create the reconstruction image that, at least to the human visual system, appears flawless as the original.

#### *Algorithm II (VEA)*

The Algorithm II (VEA) uses the following selective encryption observation: it is sufficient to encrypt only the sign bits of the DCT coefficients in an MPEG video. The Algorithm II simply xors the sign bits of the DCT coefficients with a secret  $m$ -bit binary key  $k = k_1 k_2 \dots k_m$ . The effect of this scheme is that the encryption function randomly changes the sign bits of the DCT coefficients depending on the corresponding bit value of  $k$ . Let us denote the sign bits of the DCT coefficients in an MPEG stream that belong to the same GOP (Group Of Pictures) by  $s_1 s_2 \dots s_n$ . Then, a bit  $s_i$  will not be changed if the value of the key bit  $k_{i \pmod m}$  is 0, and it will be



flipped if the value of the key bit  $k_{i \pmod m}$  is 1. The next GOP would simply reuse the secret key, which serves for the resynchronization purposes. The ability to resynchronize the video stream is important in the case of the unreliable network, transmission errors, and VCR-like functionality such as fast forwarding or rewinding.

The security of Algorithm II depends on the length of the key. The authors encourage the use of a long binary key; however, too long key may be infeasible and impractical. On the other hand, if the key is short, the system can be easily broken. If the key is as long as the video stream and it is unique and used only once that would correspond to Vernam cipher (also referred to the one-time pad), which is known to be absolutely secure. However, this is highly impractical for mass applications such as VOD (Video on Demand) and similar. On the other hand, if the key is too short, the whole method simply becomes the Vigenère-like cipher, a well-studied classical cipher for which there are many attacks developed (for example, the Kasiski analysis) [18]. In addition, Vigenère is highly sustainable to the known-plaintext attack (one can literally read off the secret key). Authors in [17] suggest the use of the pseudo-random generator that generates a stream of pseudo-random bits to be the key  $k$  of arbitrary length. The trouble with this approach is the security, randomness, and speed of this PRNG (Pseudo-Random Number Generator). The additional issues include the synchronization of the P-RNG and the secure transmission of the seed (the secret key) for the P-RNG.

#### *Algorithm III (MVEA)*

The Algorithm III (MVEA) is an improvement to the Algorithm II (VEA) described above. It includes the following additions: the sign bits of differential values of motion vectors in P- and B-frames can also be randomly changed. This type of improvement makes the video playback more

random and more non-viewable. When the sign bits of differential values of motion vectors are changed, the directions of motion vectors change as well. In addition, the magnitudes of motion vectors change, making the whole video very chaotic. The authors found that the encrypting of sign bits of motion vectors makes the encryption of sign bits of DCT coefficients in B- and P-frames unnecessary.

Furthermore, the original Algorithm III (MVEA) was designed to encrypt only the sign bits of DC coefficients in the I-frames of MPEG video sequence, while leaving the AC coefficients unencrypted. This significantly reduces the computational overhead, but it opens up new security risks. Namely, because the DC coefficient and the sum of all AC coefficients within the block are related, an adversary may use the unencrypted AC coefficients to derive the unknown (encrypted) DC coefficients [16,17]. For that reason, the authors recommend encrypting all DCT coefficients in the I-frames for applications that need higher level of security.

Just like the Algorithm II (VEA), the algorithm III (MVEA) relies on the secret  $m$ -bit key  $k$ . Also, the resynchronization is done at the beginning of a GOP. Unfortunately, the fundamental security issues and problems that are applicable to VEA are also applicable to MVEA.

#### *Algorithm IV (RVEA)*

Finally, the Algorithm IV (RVEA) is significantly more secure approach than the previous three algorithms. This approach is considered to be robust under both ciphertext-only attack and known-plaintext attack. The difference between RVEA and MVEA/VEA algorithms is that RVEA uses conventional symmetric key cryptography to encrypt the sign bits of DCT coefficients and the sign bits of motion vectors. The conventional cryptosystems are well mathematically understood, and thoroughly tested by the experts in the field, which definitely

adds on to the security aspect of RVEA. The selective approach significantly speeds up the process of conventional encryption by only encrypting certain sign bits in the MPEG stream. The experiments show that the encryption quality is quite good considering the amount of information changed.

In the Algorithm IV (RVEA), the sign bits of DCT coefficients and motion vectors are simply extracted from the MPEG video sequence, encrypted using a fast conventional cryptosystem such as AES, and then restored back to their original position in the encrypted form. The effect of this is similar to VEA/MVEA where the sign bits are either flipped or left unchanged. The authors limited the number of bits for encryption to at most 64 for each MPEG stream macroblock, for the purposes of reducing and bounding the computation time. Next, we describe exactly how these sign bits are selected for encryption.

Each MPEG video slice consists of one or more *macroblocks*. The macroblock corresponds to a 16x16 pixel square, which is composed of four 8x8 pixel luminance blocks denoted by  $Y_1, Y_2, Y_3$  and  $Y_4$ , and two 8x8 chrominance blocks  $Cb$  and  $Cr$ . Each of these six 8x8 blocks can be expressed as a sequence  $ba_1a_2...a_n$ , where  $n$  is at most 64 since  $b$  is the code for DC coefficient and  $a_i$  is the code for a non-zero AC coefficient. Then, for each such 8x8 block, we can define the sequence  $\beta\alpha_1\alpha_2...\alpha_n$ , that corresponds to the sign bits of the matching DCT coefficients  $b, a_1, a_2, \dots$ , and  $a_n$ . Figure 7 shows the order of selection of the sign bits for each macroblock. The obvious reason for this selection order is that the DC and higher order AC coefficients are carrying much more information than the low-order AC coefficients.

In conclusion, RVEA only encrypts the fraction (typically about 10%) of the whole MPEG video by using the conventional secure cryptographic schemes such as DES, IDEA, AES, etc. Therefore, the Algorithm IV (RVEA) is a much better method than the previous three algorithms

in terms of security. Furthermore, it saves up to 90% of the computation time comparing to the naive approach.

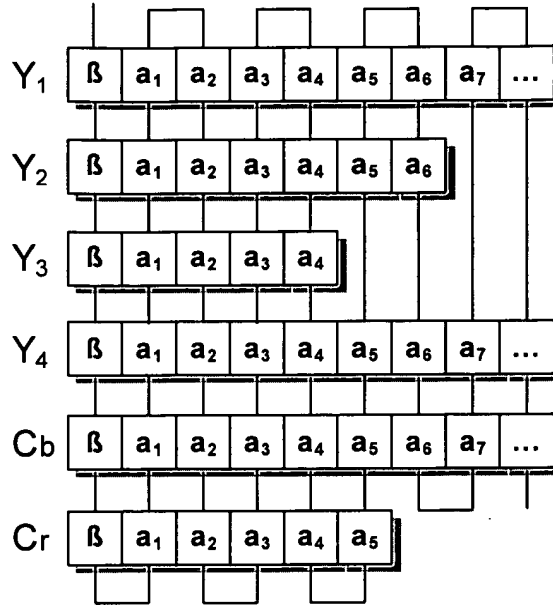


Figure 7. The bit selection order in RVEA [16,17].

#### 4.2.6 Video Encryption Methods by Alattar, Al-Regib and Al-Semari, 1999

In 1999, Alattar, Al-Regib and Al-Semari presented the three methods for selective video encryption based on DES cryptosystem [22]. These methods, called simply *Method I*, *Method II* and *Method III*, were computationally improved versions of the previous work from two of the co-authors [21], which is referred to as *Method 0*.

The first algorithm (Method 0), proposed by Alattar and Al-Regib in [21], essentially encrypts all macroblocks from I-frames and the headers of all prediction macroblocks using DES cryptosystem. This method performs relatively poorly because encryption is carried out on 40%-79% of the MPEG video stream [34].

In Method I, the data of every  $n^{\text{th}}$  macroblock from the I-frame of MPEG video stream is encrypted using DES cryptosystem, while the information from the all other I-frame macroblocks is left unencrypted. The value of  $n$  was not specified, and it can be chosen depending on the application needs. If the value of  $n$  is 2 then the encryption is performed on approximately a half of all I-frame macroblocks, but the security level is higher. On the other hand, if the value of  $n$  is higher, the computational savings are bigger, yet the security level is lower. An important observation is that even though the certain number of I-macroblocks is left unencrypted, they are not expected to reveal any information about the encrypted ones [22]. However, this method does not hide the motion information, and the authors suggest an improved algorithm, which will be discussed next.

To improve the security of Method I, Alattar, Al-Regib and Al-Semari suggested Method II, which additionally encrypts the headers of all predicted macroblocks using DES. Since DES is a block cipher that operates on 64-bit blocks, a 64-bit segment starting from the header of a predicted macroblock is processed in the beginning. This segment may include exactly the whole header (which is the rare case when header size is equal to 64 bits), a part of the header (when header size is larger than 64 bits), or the whole header along with the part of the macroblock data (when the header size is smaller than 64 bits). In the case when the encrypted segment contains a part of the header, an adversary would have serious problems with synchronization, which adds to the security regarding motion vectors [22]. The security is further increased if the encrypted segment also contains a part of the macroblock data. The computation performed using Method II is clearly faster than that of the Method 0, but slower than that of Method I.

Finally, Alattar, Al-Regib and Al-Semari proposed Method III to reduce the amount of computation from Method II. Namely, instead of encrypting all predicted macroblocks, the

encryption in Method III is performed on every  $n^{\text{th}}$  predicted macroblock, along with encrypting every  $n^{\text{th}}$  I-macroblock.

#### **4.2.7 Partial Encryption Algorithms for Videos by Cheng and Li, 2000**

The partial encryption schemes for still images introduced by Cheng and Li are also further extended to the videos [23]. The approaches proposed by Cheng and Li are not suitable for JPEG image compression, and thus naturally also not suitable for the MPEG video compression standard. Instead, the partial encryption algorithms are designed for the video compression methods, which use either quadtree compression or wavelet compression based on zerotrees for the video sequence intraframes, motion compensation, and residual error coding. For example, the partial encryption is applicable to the videos that are based on the Set Partitioning In Hierarchical Trees (SPIHT) image compression algorithm, which is an application of zerotree wavelet compression.

Cheng and Li's partial encryption algorithms are designed to disguise the intraframes (I-frames), the motion vectors, and the residual error code of the given video sequences. In both quadtree compression and wavelet compression based videos, all I-frames are encrypted using the previously discussed methods for partial encryption of still images by Cheng and Li [23].

In addition, it is also important to encrypt the motion vectors. If the motion vector information is unencrypted, the adversary may be able to use an image frame to obtain approximations to the successive frames. Almost all motion estimation algorithms divide the frame into blocks and try to predict their movement (the position in the next frame) by constructing the estimated motion vector for each block. The blocks that belong to the same large object often have identical motion vectors and it is efficient to encode these vectors together. The authors restrict to those

video encryption algorithms that use a quadtree for merging these blocks [23]. Then, quadtree partial encryption is used to encrypt the motion vectors.

Finally, for the security purposes it is important to encrypt the residual error as well. Unencrypted residual error may reveal the outline of a moving object. The residual error is often treated as an image frame and then compressed using some standard image compression algorithm. Again, we restrict ourselves to video compression algorithms that use either quadtree or wavelet based image compression algorithm to compress the residual error frames. Thus, partial encryption schemes for both quadtree and wavelet compression can be applied to the residual error encryption.

#### **4.2.8 MHT-Encryption Scheme and MSI-Coder by Wu and Kuo, 2000 and 2001**

In their recent work [24,25], Wu and Kuo proposed two selective encryption algorithms for MPEG video sequences: *MHT-encryption scheme* (where MHT stands for Multiple Huffman Tables), and *MSI-coder* (where MSI stands for Multiple State Indices).

The MHT-encryption scheme is based on changing the standard Huffman table into a different one based on a secret key. Shi, Wang and Bhargava's Algorithm I, which was discussed above, proposed the similar idea. The basic procedure for generating the entropy code based on different Huffman tree (the "encryption") is summarized in the following three steps:

- (1) Generate  $2^k$  different Huffman tables, numbered from 0 to  $2^k - 1$ .
- (2) Generate a random vector  $P = (p_1, p_2, \dots, p_n)$ , where each  $p_i$  is a  $k$ -bit integer ranging from 0 to  $2^k - 1$ .

- (3) For the  $i^{th}$  symbol in the Huffman entropy encoding stage, use the Huffman table indexed by  $p(i - 1 \pmod{n}) + 1$  to encode it.

For the purposes of not affecting the compression ratio, it is important to select optimal Huffman tables that perform similarly to the standard one. This, of course, creates additional constraint that may be a security risk [18]. The authors propose creating a number of so-called training multimedia (images or audio data) that can be used to represent majority of the multimedia data in the world, so that the associated Huffman code that can be easily generated is optimal for the general use. The authors' experimental results show relatively small increase in the output images on average, which means that in this approach the compression performance will be satisfactory, even though the symbols are chosen from the multiple Huffman tables.

Another method for obtaining optimal Huffman trees is proposed in [24,25]. Namely, only 4 base optimal Huffman trees are generated, while the other optimal tables are produced by what is referred to as a *Huffman tree mutation process*. The label pairs are permuted using the secret permutation, as illustrated by the example in Figure 8. Clearly, there is no change in the optimality. In addition, the authors propose two slight security enhancements for the MHT-encryption scheme to increase the resistance against known-plaintext and chosen-plaintext attacks (see [25]).

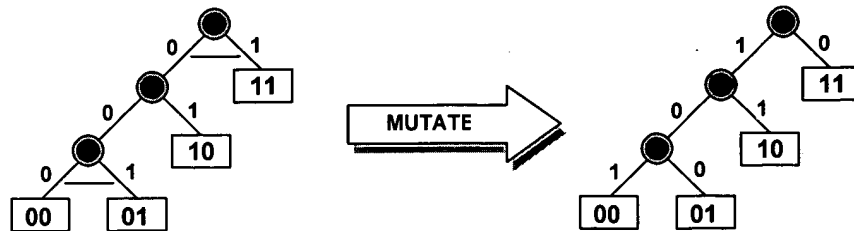


Figure 8. The Huffman tree mutation process [24,25].



The second method (MSI-coder) is designed for video codecs that use QM coding instead of the Huffman coding. The QM coder is an adaptive coder based on low-cost probability estimation. It dynamically adjusts the statistical model to a received binary sequence symbols, whose probability is updated at a low computational cost via table look-up. In the standard QM coder there is a total of 113 possible values for the state index, whose initial value is 0 indicating the equal probabilities of 0's and 1's. Since there are only 113 possibilities to initialize the state index, initializing it to a different "secret" value is pretty useless. Therefore, the MSI-coder uses 4 indices, which are initially set to different secret values, and used alternatively in a secret order. MSI-coder consists of the following 4 steps:

- (1) Generate a random key  $K = \{(s_0, s_1, s_2, s_3), (p_0, p_1, \dots, p_{n-1}), (o_0, o_1, \dots, o_{n-1})\}$ , where each  $s_i$  is a 4-bit integer, while each  $p_i$  and  $o_i$  is a 2-bit integer.
- (2) Initialize four state indices  $(I_0, I_1, I_2, I_3)$  to  $(s_0, s_1, s_2, s_3)$ .
- (3) To encode the  $i^{th}$  bit from the input, we use the index  $I_{p_i \pmod{n}}$  to determine the probability estimation value  $Q_e$ .
- (4) If the state update is required after encoding the  $i^{th}$  bit from the input, all state indices are updated except for  $I_{o_i \pmod{n}}$ .

The not-so-obvious step 4 is included to ensure that the state indices will become different even if they become the same at some point. By experiments, Wu and Kuo showed that the MSI encoded data is increased in size by only 0.82% - 4.16% when compared to the data encoded with the original QM coder. Like the previous scheme, the MSI-coder can similarly be slightly enhanced against the known-plaintext and chosen-plaintext attacks [25].

#### **4.2.9 Format-Compliant Configurable Encryption by Wen et al., 2002**

This approach, introduced in [26], is generalizing the ideas of selective encryption into format-compliant method. It stresses the importance of maintaining the compliance to a standard (such as MPEG-4 codec). In this model, the data is divided into information-carrying and not information-carrying portions. We only need to encrypt the information-carrying fields. These fields are either fixed length code (FLC) codewords, or variable length code (VLC) codewords. To achieve the format compliance, we extract the bits that are chosen to be encrypted, concatenate them, and then encrypt with secure scheme such as DES. Finally, we put the encrypted bits back to their original positions. For FLC coded fields, this operation most likely creates compliant bit-stream. If it doesn't, we apply same approach for VLC coded fields. For VLC coded fields, encrypting concatenated codewords may not result in another valid codeword. In order to still maintain compliance, we assign a fixed length index to each codeword in VLC codeword list, encrypt the index concatenation, and map it back to the codewords. This, however, introduces the overhead, but the percentage of overhead is content-dependent. In their proposal, Wen et al. stress the importance of preserving the format of standard multimedia codecs when including the additional filters such as the encryption and decryption.

#### **4.2.10 Selective Scrambling Algorithm by Zeng and Lei, 2002**

Zeng and Lei proposed the frequency domain scrambling algorithm that groups the transform coefficients into blocks or segments that undergo some or all of the following three operations: (1) selective bit scrambling, (2) block shuffling, and (3) block rotation [27].

Most of the video/image compression algorithms are based on either wavelet transform, or discrete cosine transform (DCT). Therefore, the selective scrambling algorithm proposed by

Zeng and Lei was designed for two types of compressions: wavelet transform based and 8x8 DCT based.

In the case of the wavelet transform based codecs, the selective bit scrambling is performed on the sign bits since they are not highly compressible. Other kinds of bits are refinement bits and significance bits. Significance bits are the worst candidates for selective scrambling since they have the lowest entropy, and therefore they are highly compressible. On the other hand, refinement bits are somewhere in the middle as far as the compressibility, and thus they can be scrambled too, but the degradation level is not as high as in the sign bit scrambling. In the block shuffling procedure, each subband is divided into a number of blocks of equal size, but for different subbands the blocksize can vary. These blocks can be shuffled using the table that is generated by some secret key. Visual effects of this procedure are dramatic, while the output data increases by only about 5% [27]. Finally, the set of blocks can further be rotated by a cyclic shift controlled by the secret key.

For 8x8 DCT based algorithms, each I-frame is divided into segments, each containing several macroblocks. Within the each segment DCT coefficients with the same frequency location are shuffled. In addition, sign bits of each coefficient can be encrypted. They are flipped “randomly” according to some secret key. The authors suggest that scrambling the P- and B-frames, as well as the motion vectors, is a good idea for security purposes, since they give some information about the original I-frames. If that is too computationally expensive, at least the I-blocks in P- and B-frames should be scrambled.

## 5. IMAGE ENCRYPTION TECHNIQUES

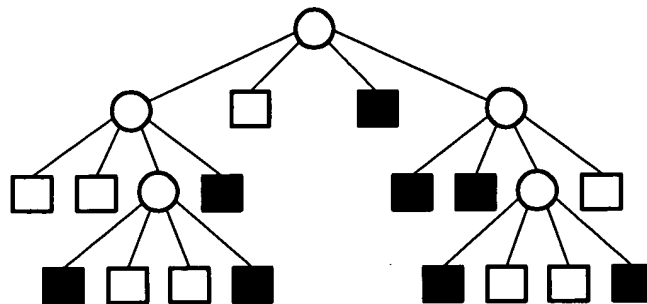
When dealing with still images, the security is often achieved by using the naive approach to completely encrypt the entire image. However, there are number of applications for which the naive based encryption and decryption represents a major bottleneck in communication and processing. For example, a limited bandwidth and processing power in small mobile devices calls for a different approach. Additionally, different image encryption techniques are used as a basis for selective video encryption. In this section, we introduce a few newly proposed techniques for image encryption, based on encrypting only certain parts of the image in order to reduce the amount of computation. This is referred to as *selective image encryption*. A similar idea was already explored in the previous section.

### 5.1 Partial Encryption Algorithms by Cheng and Li, 2000

In [23], Cheng and Li proposed partial encryption methods that are suitable for images compressed with two specific classes of compression algorithms: (1) quadtree compression algorithms, and (2) wavelet compression algorithms based on zerotrees. The encryption/decryption function is not specified, but in general, the user can select the conventional cryptosystem such as IDEA, AES, etc.

The quadtree image compression produces the quadtree structure and the parameters describing each block in the tree. For the simplicity of argument, it is assumed that the only parameter that describes each block is the average intensity. The intensity for each block does not provide enough information about the original image, but the quadtree decomposition allows the reconstruction of outlines of objects in the original frame [23]. Therefore, the quadtree

encryption method proposed by Cheng and Li encrypts only the quadtree structure, while the block intensities, located at leaf nodes of a quadtree, are left unencrypted. The quadtree partial encryption can be applied to both lossless and lossy image compression. Another consideration is the ordering of the leaf nodes for the transmission. Figure 6 illustrates the different leaf orderings to be discussed. The four branches of each tree node in Figure 6 correspond to NE (North-East), SW (South-West), SE (South-East), and NE (North-East) quadrant in that order, while the black leaf node has value 0 and white leaf node has value 1. Vulnerability to certain cryptanalytical attacks exists if the ordering of leaf nodes is done using the Leaf Ordering I, where leafs are encoded via the inorder traversal of the quadtree. If we would apply Leaf Ordering I to the tree from Figure 6, the result would be binary sequence 0010011011110010. Therefore, the authors suggest using the Leaf Ordering II, where leafs are encoded via the opposite of breadth-first traversal of the tree. This increases the security level [23]. For illustration, applying the Leaf Ordering II to the quadtree from Figure 9 would result in the binary sequence 1111000001100101.



**Figure 9.** An example of a quadtree for black and white (binary) image [23]

- Wavelet compression algorithm based on zerotrees generally transmits the structure of the zerotree, along with the significant coefficients. Typical example of this kind of compression algorithm is the Set Partitioning In Hierarchical Trees (SPIHT) compression algorithm, which transmits the significance of the coefficient sets that correspond to the trees of coefficients. The

SPIHT algorithm uses the significance of the coefficient sets to reconstruct the zerotree structure. In addition, the structure of the tree strongly affects the execution of SPIHT algorithm. The SPIHT encoded image contains different types of data such as the sign bits, the refinement bits, and the significance bits (significance of pixels and significance of sets). Even the small amount of incorrect information at the beginning of the encoded block containing the significance bits causes the failure in the decoding process. Incorrect significance bits often cause the misinterpretation of future bits, unlike the incorrect sign bits or refinement bits, which do not. Therefore, Cheng and Li propose encrypting only the significance information of pixels and sets, as well as the initial threshold parameter  $n$  that determines which coefficients are significant [23]. Furthermore, the wavelet transform creates a hierarchy of coefficient bands called *pyramid decomposition*, and the number in the band label is referred to as the *pyramid level*. The authors restrict to encrypting only those significance bits that are in the two highest pyramid levels, since all other pixels and sets are derived by decomposing the sets from the highest two pyramid levels. The information about the significant bits from the first two pyramid levels cannot be deduced just by observing the lower levels.

## **5.2 Selective Encryption Methods for Raster and JPEG Images by Droogenbroeck and Benedett, 2002**

In 2002, Droogenbroeck and Benedett proposed the selective encryption methods for uncompressed (raster) images and compressed (JPEG) images [28].

An uncompressed (raster) grey level image defines 8 bitplanes. The highest (most significant) bitplanes are highly correlated to the original gray level image. On the other hand, the least significant bitplanes appear random-like. Encrypting only the bitplanes that contain nearly uncorrelated values would decrease the vulnerability to the known-plaintext attacks [28]. The

authors propose the encryption scheme that is consisted of xoring the selected bitplanes with a key that has the same number of bits as the bits that are to be encrypted. According to Droogenbroeck and Benedett, at least 45 least significant bitplanes should be encrypted to achieve the satisfactory visual degradation of the image. It is important to note that the partial degradation of the image is not sufficient for applications where high security is a must.

The second method is designed to selectively encrypt the JPEG compressed images. The Huffman entropy encoding creates the symbols based on the run-length coding. In particular, zero coefficients are encoded into the symbols that contain the run of zeros and the magnitude categories for the non-zero coefficients that terminate the runs. These symbols are encoded with the 8-bit Huffman codewords, followed by the appended bits that specify the sign and magnitude of the non-zero coefficients. In the proposed method, only the appended bits that correspond to the selected AC coefficients are encrypted. The DC coefficients are left unencrypted, since their values are highly predictable [28]. On the other hand, the codewords are left unencrypted for the synchronization purposes.

### **5.3 Selective Bitplane Encryption Algorithm by Podesser, Schmidt and Uhl, 2002**

In [35], Podesser, Schmidt and Uhl proposed a selective encryption algorithm for the uncompressed (raster) images, that is quite opposite from the first method by Droogenbroeck and Benedett [28]. In the raster image that consists of 8 bitplanes, Schmidt and Uhl's algorithm encrypts only the most significant bitplanes. The proposed underlying cryptosystem for this method was AES. However, without loss of generality, any fast conventional cryptosystem may be chosen instead.

After performing the experiments, Podesser, Schmidt and Uhl came to the same conclusion in [35] as Droogenbroeck and Benedett did in [28]. That is, encrypting only the most significant bitplane is not secure. Podesser, Schmidt and Uhl argue that MSB bitplane can be reconstructed with the aid of the unencrypted remaining bitplanes. Therefore, they suggest encrypting at least 2 or 4 bitplanes. Encrypting only two bitplanes is sufficient if severe alienation of the image data is acceptable, while encrypting four bitplanes provides high security. It is up to the user to determine whether the degradation method by encrypting only two bitplanes is sufficient for the given application, or more secure approach of encrypting four bitplanes is needed.

## **6. AUDIO AND SPEECH ENCRYPTION TECHNIQUES**

In many applications, the audio sequences need confidentiality during transmission. Sometimes it is enough to apply the naive approach, but in many instances this is too computationally expensive (for example, in small mobile devices). As far as the security is concerned, perhaps the most important type of audio data is speech. Unlike in the case of music files and similar entertainment audio sequences, in many applications speech requires substantial level of security. This section discusses the methods for speech protection, as well as the protection of general audio compressed sequences such as MP3.

### **6.1 ENCRYPTION OF COMPRESSED SPEECH**

Traditional speech scrambling has a long history. Like in the case of analog video signal, the early work was based on analog devices that simply permute speech segments in the time domain



or distort the signal in the frequency domain by applying inverters and filter banks. These schemes are very insecure by today's computing standards [24]. Today's research is shifted towards securing the speech in the digital form, by applying partial or selective encryption [24, 29, 30].

#### **6.1.1 Selective Encryption Algorithm for G.723.1 Speech Codec by Wu and Kuo, 2000**

One of the most popular digital speech codecs is the ITU recommendation G.723.1 compression standard. It has a very low bit rate, and it is extremely suitable for voice communications over the packet-switching based networks. It is also a part of the ITU H.324 standard for video-conferencing/telephony over the regular public telephone lines.

The compression is based on the analysis-by-synthesis method. The encoder incorporates the entire decoder unit, which synthesizes a segment of speech according to given input coefficients. The encoder then changes these coefficients until the difference between the original speech and the synthesized speech is within the acceptable range. The decoding is performed with three different decoders: LSP decoder, pitch decoder and excitation decoder, and the G.723.1 coefficients can be categorized depending on the decoder they are fed to. In addition, this codec can work in either 6.3 Kbps or 5.3 Kbps modes.

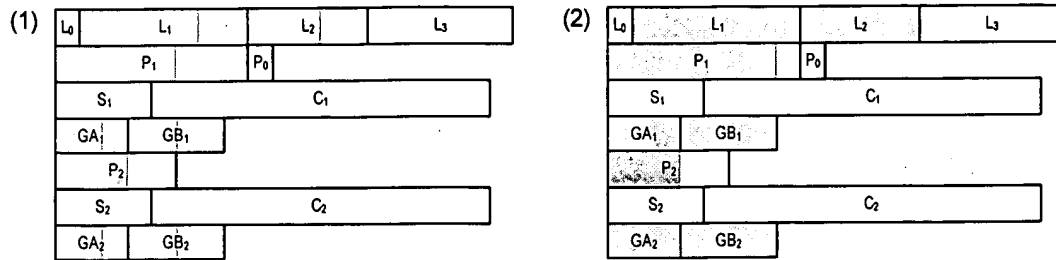
In [24], Wu and Kuo suggest applying selective encryption to the most significant bits of all important G.723.1 coefficients. They identified the following coefficients as the important ones: the LSP codebook indices, the lag of pitch predictor, the pitch gain vectors, the fixed codebook gains, and the VAD mode flag. The total number of selected bits for encryption is 37 in each frame, which is less than 1/5 of the entire speech stream at the 6.3 Kbps rate, and less than 1/4 of the entire speech stream at the 5.3 Kbps rate.

### **6.1.2 Perception-Based Partial Encryption Algorithm by Servetti and De Martin, 2002**

In 2002, Servetti and De Martin published a perception-based algorithm for partial encryption of telephone bandwidth speech [29]. The algorithm was implemented for the ITU-T G.729 codec for a rate of 8 Kbps.

Servetti and De Martin suggested two methods for partial telephony speech encryption. The first method was aimed to have low-security, but high bit rate (similar to the degradation schemes for videos and images). The goal of this method was to degrade the speech to enough to prevent immediate eavesdropping. However, more substantial cryptanalysis could reveal the encrypted speech. The second algorithm encrypts more of the bit-stream, and its goal is to provide more security. Servetti and De Martin argue that even though it encrypts only about a half of the bit-stream, the algorithm's security level is comparable to that of the naive algorithm.

There are total of 15 segments from the ITU-T G.729 codec output:  $L_0$  (1 bit),  $L_1$  (7 bits),  $L_2$  (5 bits),  $L_3$  (5 bits),  $P_1$  (8 bits),  $P_0$  (1 bit),  $S_1$  (4 bits),  $C_1$  (13 bits),  $GA_1$  (3 bits),  $GB_1$  (4 bits),  $P_2$  (5 bits),  $S_2$  (4 bits),  $C_2$  (13 bits),  $GA_2$  (3 bits), and  $GB_2$  (4 bits). Rather than describing it in words, the selected bits for encryption in Servetti and De Martin's low and high security algorithms are shown in Figure 10. The experiments showed that by applying the high security selective encryption algorithm, the speech is highly scrambled, it cannot be reconstructed from the known bits, and the total computational saving is more than 50%.



**Figure 10.** Partial encryption for G.729 speech codec (grayed bits are selected for encryption): (1) low security algorithm, and (2) high security algorithm [29].

## 6.2 ENCRYPTION OF COMPRESSED AUDIO

There are numerous applications where the general audio data needs to be protected, and the expensive naive approach might be infeasible. This demand created some research initiatives towards developing selective encryption approaches for compressed audio streams.

### 6.2.1 MP3 Security Methods by Thorwirth, Horvatic, Weis and Zhao, 2000

Thorwirth et al., proposed a selective encryption algorithm for perceptual audio coding (PAC) based compression standards, such as MPEG-I Layer-3 (MP3) [36]. In their proposal, the authors concentrated on analyzing encryption of MP3 encoded audio files.

In the late 1980's, the researchers at Fraunhofer Institute developed the audio coding technique called MPEG-I Layer-3, or simply MP3. This codec achieved the stunning compression ratio of 1:10 - 1:12, while still maintaining the CD sound quality. It is a perception audio codec (PAC) that uses the perceptual masking algorithms to discard the redundancy from the raw audio digital signal. All components of the raw audio signal that are inaudible to the human hearing system

are identified as the redundant data by the perceptual models. The compression in MP3 audio standard is based on the Huffman entropy code.

Hearable frequency spectrum is divided into the segments called the *audio quality layers*. The 20Hz-4KHz range represents the lowest audio quality layer, while the CD quality range is 20Hz-22KHz. The authors propose encrypting the audio quality layers associated with the compressed audio data, in order to enforce audio quality control by means of encryption. The algorithm identifies the frequency spectrum boundaries that are used to determine the audio quality layers. Each known layer is then grouped into the blocks of equal size and a block cipher is applied. After encryption stage, the encrypted data can be easily plugged back to the MP3 bit-stream, thus preserving the format. Such encrypted MP3 sequences are decodable and playable by any valid MP3 player [36].

## 7. SUMMARY

In this chapter, many of the current important multimedia encryption techniques were presented and analyzed. In brief, the best way of protecting multimedia data is by means of the naive algorithm; i.e., by encrypting the entire multimedia bit sequence using a fast conventional cryptosystem. Yet, in many instances this is not possible due to the expensive computational overhead introduced by the encryption and decryption stages. Much of the past and current research targets encrypting only a carefully selected part of the multimedia bit-stream in order to reduce the computational load, and yet keep the security level high. Many of the proposed schemes only achieved moderate to low security, which may find applications in which quality degradation is preferred over absolute security. However, only few of the proposed methods

promise to achieve substantial security, which is the number one requirement in many multimedia applications. It is also worthwhile mentioning that many of the above proposed audiovisual encryption techniques are flexible in terms of selecting the underlying cryptosystem, regardless of the choice made by the authors. In general, a well-studied, fast and secure conventional cryptosystem should be chosen. Surely, AES is a good candidate, but there are numerous other successful modern cryptosystems with similar and, in some aspects, even better performances.

Further research should be directed towards developing substantially secure encryption schemes for high bit rate and high-quality audiovisual data. Furthermore, the experts should investigate the security aspects of the newly proposed multimedia encryption techniques.

## REFERENCES

1. IEEE Transactions on Circuits and Systems for Video Technology: Special Issue on Authentication, Copyright Protection, and Information Hiding, Vol. 13, No. 8, August 2003.
2. B. Furht and D. Socek, "Multimedia Security: Encryption Techniques," IEC Comprehensive Report on Information Security, International Engineering Consortium, Chicago, IL, 2003.
3. A.M. Eskicioglu, "Protecting Intellectual Property in Digital Multimedia Networks," IEEE Computer, July 2003, pp. 39-45.
4. X. Liu and A.M. Eskicioglu "Selective Encryption of Multimedia Content in Distribution Networks: Challenges and New Directions," IASTED International Conference on Communications, Internet and Information Technology (CIIT 2003), Scottsdale, AZ, November 17-19, 2003.
5. P.C. van Oorschot, A.J. Menezes, and S.A. Vanstone, "Handbook of Applied Cryptography," CRC Press, Inc., 1997.
6. D.R. Stinson, "Cryptography Theory and Practice," CRC Press, Inc., 2002.
7. T.B. Maples and G.A. Spanos, "Performance study of selective encryption scheme for the security of networked real-time video," in Proceedings of the 4th International Conference on Computer and Communications, Las Vegas, NV, 1995.
8. G.A. Spanos and T.B. Maples, "Security for Real-Time MPEG Compressed Video in Distributed Multimedia Applications," in Conference on Computers and Communications, 1996, pp. 72-78.
9. J. Meyer and F. Gadegast, "Security Mechanisms for Multimedia Data with the Example MPEG-1 Video," Project Description of SEC MPEG, Technical University of Berlin, Germany, May 1995.
10. L. Tang, "Methods for Encrypting and Decrypting MPEG Video Data Efficiently," Proceedings of the 4th ACM International Multimedia Conference, Boston, MA, November 18-22, 1996, pp. 219-230.
11. I. Agi and L. Gong, "An Empirical Study of Secure MPEG Video Transmission," Proceedings of the Symposium on Network and Distributed Systems Security, IEEE, 1996.
12. L. Qiao and K. Nahrstedt, "A New Algorithm for MPEG Video Encryption," Proceedings of the 1st International Conference on Imaging Science, Systems and Technology (CISST '97), Las Vegas, NV, July 1997, pp. 21-29.
13. L. Qiao and K. Nahrstedt, "Comparison of MPEG Encryption Algorithms," International Journal on Computer and Graphics, Special Issue on Data Security in Image Communication and Network, 22(3), 1998.

14. L. Qiao, K. Nahrstedt, and I. Tam, "Is MPEG Encryption by Using Random List Instead of Zigzag Order Secure?" IEEE International Symposium on Consumer Electronics, December 1997, Singapore.
15. C. Shi and B. Bhargava, "A Fast MPEG Video Encryption Algorithm," Proceedings of the 6th International Multimedia Conference, Bristol, UK, September 12-16, 1998.
16. C. Shi, S.-Y. Wang and B. Bhargava, "MPEG Video Encryption in Real-Time Using Secret key Cryptography," 1999 International Conference on Parallel and Distributed Processing Techniques and Applications (PDPTA'99), Las Vegas, NV, June 28 - July 1, 1999.
17. B. Bhargava, C. Shi, and Y. Wang, "MEPG Video Encryption Algorithms", August 2002, available at <http://raidlab.cs.purdue.edu/papers/mm.ps>
18. T. Seidel, D. Socek, and M. Sramka, "Cryptanalysis of Video Encryption Algorithms," to appear in Proceedings of The 3<sup>rd</sup> Central European Conference on Cryptology TATRACRYPT 2003, Bratislava, Slovak Republic, 2003.
19. T. Seidel, D. Socek, and M. Sramka, "Parallel Symmetric Attack on NTRU using Non-Deterministic Lattice Reduction," to appear in Designs, Codes and Cryptography, issue on Proceedings of the Third Pythagorean Conference, Rhodes, Greece, 2003.
20. N. Howgrave-Graham, P. Nguyen, D. Pointcheval, J. Proos, J.H. Silverman, A. Singer, and W. Whyte, "The Impact of Decryption Failures on the Security of NTRU Encryption," in Proceedings of Crypto 2003, Santa Barbara, CA, 2003.
21. A. Alattar and G. Al-Regib, "Evaluation of selective encryption techniques for secure transmission of MPEG video bit-streams," in Proceedings of the IEEE International Symposium on Circuits and Systems, vol. 4, pp IV-340-IV-343, 1999.
22. A. M. Alattar, G. I. Al-Regib and S. A. Al-Semari, "Improved Selective Encryption techniques for Secure Transmission of MPEG Video Bit-Streams," Proceedings of the 1999 International Conference on Image Processing (ICIP '99), Vol. 4, Kobe, Japan, October 24-28, 1999, pp. 256-260.
23. H. Cheng and X. Li, "Partial Encryption of Compressed Images and Video," IEEE Transactions on Signal Processing, 48(8), 2000, pp. 2439-2451.
24. C.-P. Wu and C.-C. J. Kuo, "Fast Encryption Methods for Audiovisual Data Confidentiality," SPIE International Symposia on Information Technologies 2000, Boston, MA, November 2000, pp. 284-295.
25. C.-P. Wu and C.-C. J. Kuo, "Efficient Multimedia Encryption via Entropy Codec Design," Proceedings of SPIE Security and Watermarking of Multimedia Content III, Volume 4314, San Jose, CA, January 2001.
26. J. Wen, M. Severa, W. Zeng, M. Luttrell, and W. Jin, "A Format-Compliant Configurable Encryption Framework for Access Control of Video," IEEE Transactions of Circuits and Systems for Video Technology, Vol. 12, No. 6, June 2002, pp. 545-557.
27. W. Zeng and S. Lei, "Efficient Frequency Domain Selective Scrambling of Digital Video," IEEE Transactions on Multimedia, Vol. 5, No. 1, March 2002, pp. 118-129.
28. M. Van Droogenbroeck and R. Benedett, "Techniques for a Selective Encryption of Uncompressed and Compressed Images," Proceedings of Advanced Concepts for Intelligent Vision Systems (ACIVS) 2002, Ghent, Belgium, September 9-11, 2002.
29. A. Servetti and J.C. De Martin, "Perception Based Partial Encryption of Compressed Speech," IEEE Transaction on Speech and Audio Processing, Vol. I, No. 8, 2002.
30. A. Servetti, C. Testa and J. C. De Martin, "Frequency-Selective Partial Encryption of Compressed Audio," IEEE International Conference on Acoustics, Speech and Signal Processing, Hong-Kong, April 6-10, 2003.
31. D. McGrew, M. Naslund, K. Norman, R. Blom, E. Carrara, and D. Oran "The Secure Real time Transport Protocol (SRTP)," Internet draft, 2001.
32. S. U. Shin, K. S. Sim and K. H. Rhee, "A Secrecy Scheme for MPEG Video Data Using the Joint of Compression and Encryption," Second International Workshop on Information Security (ISW '99), Kuala Lumpur, Malaysia, November 1999, Lecture Notes in Computer Science, Vol. 1729, pp. 191-201, 1999.
33. M. Wu and Y. Mao, "Communication-Friendly Encryption of Multimedia," 2002 International Workshop on Multimedia Signal Processing, St. Thomas, US Virgin Islands, December 9-11, 2002.

34. T. Lookabaugh, D. C. Sicker, D. M. Keaton, W. Y. Guo and I. Vedula, "Security Analysis of Selectively Encrypted MPEG-2 Streams," Multimedia Systems and Applications VI Conference, Orlando, FL, September 7-11, 2003.
35. M. Podesser, H.-P. Schmidt and A. Uhl, "Selective Bitplane Encryption for Secure Transmission of Image Data in Mobile Environments," 5th Nordic Signal Processing Symposium, on board Hurtigruten, Norway, October 4-7, 2002.
36. N.J. Thorwirth, P. Horvatic, R. Weis and J. Zhao, "Security methods for MP3 music delivery," Conference Record of the Thirty-Fourth Asilomar Conference on Signals, Systems and Computers, 2000, vol. 2, pp 1831-1835.
37. A. Pommer and A. Uhl, "Selective Encryption of Wavelet-Packet Encoded Image Data," ACM Multimedia Systems Journal, Special Issue on Multimedia Security, 2003.
38. J. Daemen and V. Rijmen, "AES Proposal: Rijndael", AES Algorithm Submission, September 3, 1999, available at <http://www.nist.gov/CryptoToolkit>.

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